DEPARTMENT OF THE INTERIOR
JOHN BARTON PAYNE, SECRETARY
BUREAU OF MINES
H. FOSTER BAIN, ACTING DIRECTOR

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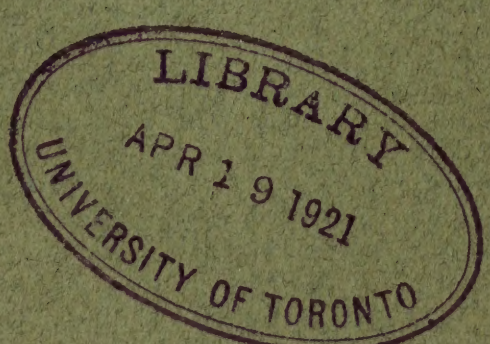
BY

CLARENCE A. WRIGHT, JAMES G. PARMELEE
and JAMES T. NORTON

[This report was prepared in cooperation with the School of Mines, University of Idaho, and the Idaho State Bureau of Mines and Geology]



WASHINGTON
GOVERNMENT PRINTING OFFICE
1921

Bulletin 205

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First edition. January, 1921.

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By CLARENCE A. WRIGHT and JAMES G. PARMELEE.

INTRODUCTION.

The object of this paper is to give to mining companies and to all others who are interested some idea of the possibilities in the treatment, by differential flotation, of lead-zinc ores of the Coeur d'Alene region and other districts. The purpose of these investigations is not to evolve a differential flotation process that would replace present methods of gravity concentration but rather one that could be applied to the relatively fine material and slime produced in the mills and treated unsuccessfully by gravity methods or by flotation. It is expected, of course, that the products to be obtained by differential flotation would be of much better grade than those now produced by flotation in the Coeur d'Alene mills.

In view of the fact that it has been difficult to obtain representative samples of flotation feed from the mills, owing to the necessity of shipping the material wet and free from oil or other foreign matter that might be deleterious to the differential separation of the sulphides, the writers have felt justified in running flotation tests with the mill feeds in order to ascertain whether a differential separation of the sulphides could be effected. However, two different lots of flotation feed were tested for differential flotation, and the results of tests of one of these are given in this report. It is hoped that it will be possible later to test out the flotation feed for differential flotation on a large scale in some of the mills.

This paper covers part of the investigations carried on by the United States Bureau of Mines in cooperation with the Idaho Bureau of Mines, the University of Idaho, and certain mining companies of the Coeur d'Alene region. Although the results of the tests included in this report are not to be considered final, they indicate possibilities and may suggest others leading to a solution of the problem of separating lead and zinc sulphides by differential flotation in the treatment of certain ores.

DEFINITIONS.

The following definitions of flotation have been adopted by the Bureau of Mines:

Flotation is the process or processes by which the valuable minerals in a mass of finely ground ore can be caused to float on a liquid into which the finely ground ore is fed.

Differential flotation is the flotation of one flotative mineral in the presence of another ordinarily flotative.

Preferential flotation is a special type of differential flotation in which a mixture of two flotative minerals is given a light roast in order that one may be oxidized while the other remains unchanged. Only the surface of one of the minerals is oxidized, but this suffices to keep it from floating.

ACKNOWLEDGMENTS.

The writers acknowledge their indebtedness to the mining companies of the Coeur d'Alene region for information given, for courtesies extended, and for the ores used in the tests. They are especially indebted to Francis A. Thomson, dean of the School of Mines, University of Idaho, and secretary of the Idaho Bureau of Mines, for helpful suggestions and for facilitating necessary laboratory rearrangements; to Thomas Varley, superintendent of the experiment station of the United States Bureau of Mines at Salt Lake City, Utah, for his interest and greatly appreciated advice; and to R. E. Head for his excellent work on the microscopic examination of specimens and the preparation of the photomicrographs illustrating this bulletin.

In addition, acknowledgment is made here to J. H. Jonté for the many chemical analyses of the ores and flotation products necessary for the compilation of material for this report, and to Martin S. Taylor for his assistance in running tests and performing many other duties in connection with the work.

LEAD-ZINC ORES OF THE COEUR D'ALENE REGION.

The chief metals produced from the ores of the Coeur d'Alene region are lead and zinc, with minor amounts of copper, silver, and antimony. Where the minerals are as finely disseminated as in the mines of the Pine Creek, Nine-mile, and other districts, it is almost impossible to make clean lead and zinc products by the usual methods of gravity concentration. Although at most mills a good percentage of lead and zinc is recovered in the concentrates from the jigs, fine grinding is essential to effect a reasonably clean separation of either mineral when as finely disseminated as in ores of this character. In fact, it has been found by examination under the micro-

scope that some of the lead and zinc particles are still mechanically combined in an ore that has been crushed to pass a 200-mesh screen. This fact is clearly indicated in the accompanying photomicrographs, which are described under each ore tested.

PRODUCTS OBTAINED BY PRESENT METHODS OF CONCENTRATION

The following examples will give some idea of the grade of lead-zinc ore treated and the products obtained by the present methods of concentration:

Assays of feed and concentrates.

Ore 1.	Assays.						
	Pb.	Zn.	Ag.	Fe.	Mn.	S.	Insol.
	Per cent.	*Per cent.*	*Ounces per ton.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Feed to mill	11.4	16.9	3.6	6.1	9.2	14.0	50.0
Zinc concentrates	15.4	33.4	5.0	9.3	.3	23.1	16.6

Ore 2.	Assays.		
	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*
Feed to mill	3.0	15.0	8.0
Lead concentrates	45.0	18.0	15.0
Zinc concentrates	9.0	34.5	11.0

Ore 3.	Assays.			
	Pb.	Zn.	Fe.	Ag.
	Per cent.	*Per cent.*	*Per cent.*	*Ounces per ton.*
Feed to mill	6.0	12.0	7.0	2.0
Lead concentrates from mill	50.0	12.0	7.0	16.0
Zinc concentrates from mill	14.0	35.0	5.0	5.0
Lead concentrates from tables	68.0	8.0	7.0	18.0
Zinc concentrates from tables	9.0	34.0	10.0	3.0
Lead product from retreatment of flotation concentrates on tables	65.0	10.0	7.0	15.0
Zinc product from retreatment of flotation concentrates on tables	12.0	43.0	5.0	4.0

Ore 4.	Assays.		
	Pb.	Zn.	Ag.
	Per cent.	*Per cent.*	*Ounces per ton.*
Feed to mill	5.1	5.8	1.9
Lead concentrates from jigs	49.5	10.0	12.8
Lead concentrates from tables	56.6	11.2	9.7
Zinc concentrates from tables	11.7	23.4	8.6
Feed to flotation cells	2.7	5.7	1.8
Zinc concentrates from flotation	15.6	25.4	7.8

From the above examples it is evident that considerable zinc is lost in the lead concentrates and that the zinc concentrates carry a small amount of lead. The question arises, therefore, whether or

not a cleaner separation of the minerals is commercially feasible. On the assumption that cleaner products are possible, it is necessary to determine what step should be taken to effect a better separation, whether (1) by changing and improving the present methods, as by grinding the ore finer, which would necessitate more tables, possibly a smaller number of jigs, and a somewhat larger flotation plant; or (2) by combining the first improvement with differential flotation; or (3) by giving the concentrates a flash roast followed by preferential flotation; or (4) by some hydrometallurgical process.

In order to avoid any radical changes in the present methods and equipment in the mills, it seemed advisable to experiment along the first and second lines suggested, namely, to effect a better separation of the lead and zinc minerals by differential flotation, with whatever changes in the present treatment of the ores this might necessitate, should differential flotation prove successful. It is in that direction, therefore, that the Bureau of Mines, in cooperation with the University of Idaho, the Idaho Bureau of Mines and Geology, and certain mining companies of the Coeur d'Alene region, has done most of its experimenting in order to find some method of effecting a better commercial separation. From a number of tests run on various ores to date, interesting and encouraging results have been obtained.

TESTING THE LEAD-ZINC ORES FOR DIFFERENTIAL FLOTATION.

In the experiments conducted under the direction of the United States Bureau of Mines in the University of Idaho School of Mines laboratories, the principal object in testing an ore for differential flotation was to ascertain what flotative mixture would effect the best differential separation as regards commercial practicality. Prior to the actual testing of any ore for differential flotation, however, certain preliminary tests were made that have an important bearing on subsequent treatment. This preliminary work comprised a physical examination of the ore, a screen analysis after the ore had been crushed to ½-inch size or less, and an examination under a hand lens or a binocular microscope of the finer sizes of ore to ascertain the fineness of crushing necessary to liberate most of the mineral particles. These physical tests or examinations were followed by chemical analyses of the ore and of the products obtained from the screen analyses. The more important points brought out by the preliminary examination of the ore, considered with reference to subsequent flotation testing, were the necessary degree of fineness in grinding and the chemical composition of the ore with reference to the minerals sought and the gangue constituents present.

USE OF OILS AND CHEMICALS.

After the preliminary observations were made, actual flotation tests followed. The method of procedure was first to run a series of tests with each ore, using different oils alone to determine the relative value of each as to frothing and collecting properties, and its ability to effect a mineral selection. The procedure was then repeated with a number of the more common chemicals alone. From the results obtained in these two series of tests it was ascertained what possible combinations of oils and chemicals might be expected to effect a high recovery and a good selection of mineral with the particular ore in question. Finally, many combinations of the selected oils and chemicals were tried, followed by tests using different quantities of the oils and chemicals. It should be mentioned here that many of the derivatives of both mineral and vegetable oils, such as phenol, anthracene, eugenol, and guaiacol, were also tried. Some of the oil derivatives gave good results, whereas others were more or less inactive as far as concerns differential selection and recovery.

A mixture of coal-tar creosote, alcohol, and sodium hydroxide effected a fairly good differential separation of the lead and zinc sulphides in one ore, with a fair recovery. Distillates drawn off at different temperatures from mixtures of many coal tars and alcohol were used, but the results were not much more satisfactory than with "straight" mixtures of coal tar and alcohol.

The use of alcohol and coal-tar creosote with sodium hydroxide has been mentioned in an article by W. L. Zeigler.[1] Unfortunately this mixture did not seem to be applicable to all lead-zinc ores with equally good results, as actual tests have shown. In fact, the outstanding feature of the many tests run on different ores was that each ore seemed to require a somewhat different flotative mixture and that the effect of a certain oil or flotation agent on one ore may be different on another similar ore. This is mentioned to obviate any tendency to drawing the conclusion that a flotation mixture used with one ore will produce like results with another ore of similar mineral content. It is sometimes possible, however, to remove or at least to reduce the detrimental effect of soluble compounds present by washing the ore prior to flotation.

Mixtures of gasoline and coal tars have also been tested, giving a good selection of lead with rather low recoveries. A mixture of gasoline and coal tar with a small amount of cresylic acid has been used with fair success on a commercial scale in differential flotation of a lead-zinc ore.

[1] Zeigler, W. L., Differential flotation of lead and zinc: Eng. and Min. Jour., vol. 105, Apr. 20, 1918, pp. 741–742.

The reader will note that 20 pounds of chemical have been used in some of the tests described in this paper. This quantity is employed in the preliminary tests solely to determine the effectiveness of the chemical in producing a differential selection of mineral. In larger scale work the amount of chemical or chemicals can be considerably reduced, as proved by actual tests.

OPERATING CONDITIONS.

Nearly all the flotation experiments were made with mechanical-agitation machines of the Federal-Varley type (fig. 1) with ore that was crushed dry. In testing the ores included in this report, it was found that a better recovery was possible with an ore that had been crushed wet; hence results from tests which used ore that had been crushed dry might have been improved by wet crushing.

The following table, giving comparative results of tests, emphasizes this more clearly.

TABLE 1.—*Comparison of results obtained in the treatment of lead-zinc ore after dry and wet crushing.*

[Feed: Pb, 11.4 per cent; Zn, 3.9 per cent; Fe, 11.7 per cent.]

DRY CRUSHING.

Flotation agents.	Pounds per ton.	Grade of product.			Recoveries.		
		Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Distillate from mixture of coal tar and and alcohol (1:4)	1.0						
Sodium hydroxide	1.0	53.7	10.9	4.9	72.0	48.0	6.3
Mixture of coal-tar creosote and alcohol (1:4)	1.0						
Sodium hydroxide	1.0	50.2	8.7	6.0	75.4	43.4	8.7
Mixture of coal tar and alcohol (1:4)	1.0						
Sodium hydroxide	1.0	49.9	9.0	6.2	70.0	41.7	8.3
Coal-tar creosote	.2						
Wood creosote	.3						
Sulphuric acid	10.8	36.1	8.4	9.5	80.0	60.0	20.0

WET CRUSHING.

Distillate from mixture of coal tar and alcohol (1:4)	1.0						
Sodium hydroxide	1.0	54.5	9.1	6.3	90.6	46.5	9.5
Mixture of coal tar creosote and alcohol (1:4)	1.0						
Sodium hydroxide	1.0	54.7	9.1	6.0	88.0	45.0	8.7
Mixture of coal tar and alcohol (1:4)	1.0						
Sodium hydroxide	1.0	49.0	10.4	7.7	91.0	59.5	12.9
Coal-tar creosote	.2						
Wood creosote	.3						
Sulphuric acid	10.8	39.4	11.5	9.9	95.2	84.0	22.0

All preliminary tests were run in a small single-cell machine (fig. 1), using 1,000 grams of ore for each test. When a fair selection and a fair recovery were obtained from a preliminary test, the experiment was repeated in a larger machine, using 4,000 to 5,000 grams of ore.

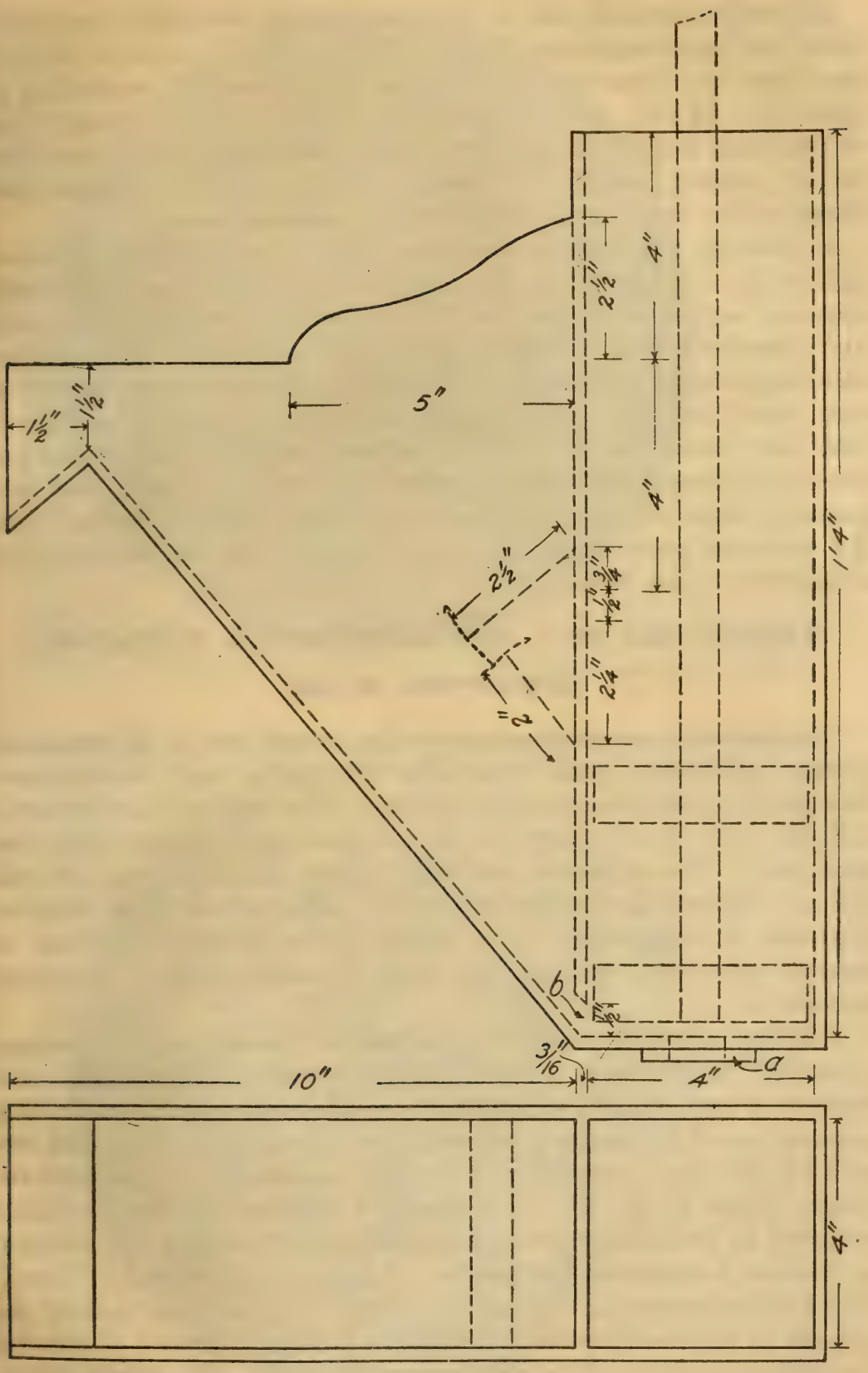


FIG. 1.—Experimental Flotation Machine. *a*, 2-inch by ¼-inch brass ring bored for 1-inch plug; *b*, slot. To be constructed of sheet lead $\frac{3}{16}$ inch thick. All joints to be water-tight and finished smooth on both sides.

Although practically all of the flotation tests described were made with mechanical-agitation machines, the type of machine utilized may have an important bearing on the differential separation of minerals. In fact, some modification of any of the existing types of machines might help to effect better differential separations than are at present possible. A study of the mechanical features and design of the machines is well worthy of consideration.

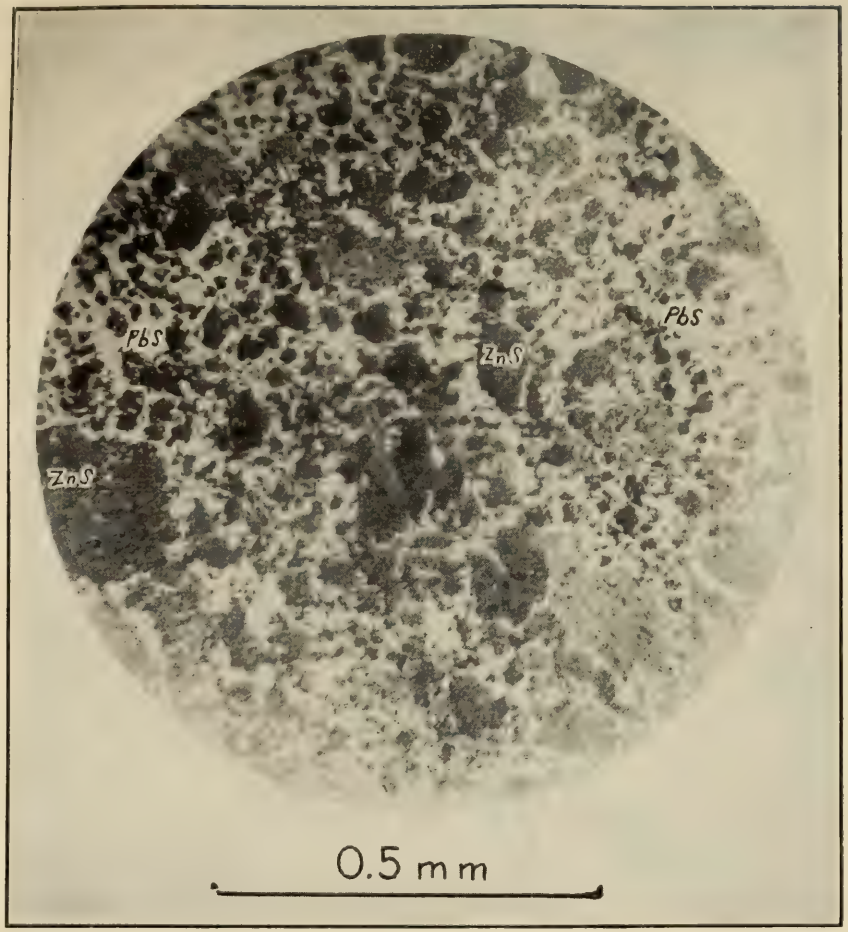
In running the tests it was found that a pulp density of about 2½:1 to 3½:1 (water to solids) seemed to give the best differential selection and mineral recovery at normal temperature. The pulp and flotative mixtures were preagitated from three to five minutes at a pulp density of about 1:1, after which the water level in the cell was raised and the agitation continued for about 10 minutes. It had been found that the bulk of the lead sulphide concentrate was drawn off during the first five minutes, but the agitation was continued in order that the time factor might be the same for each test. All products were obtained direct from a single cell without any attempt to clean them.

TESTING ORE NO. 1 FOR DIFFERENTIAL FLOTATION.

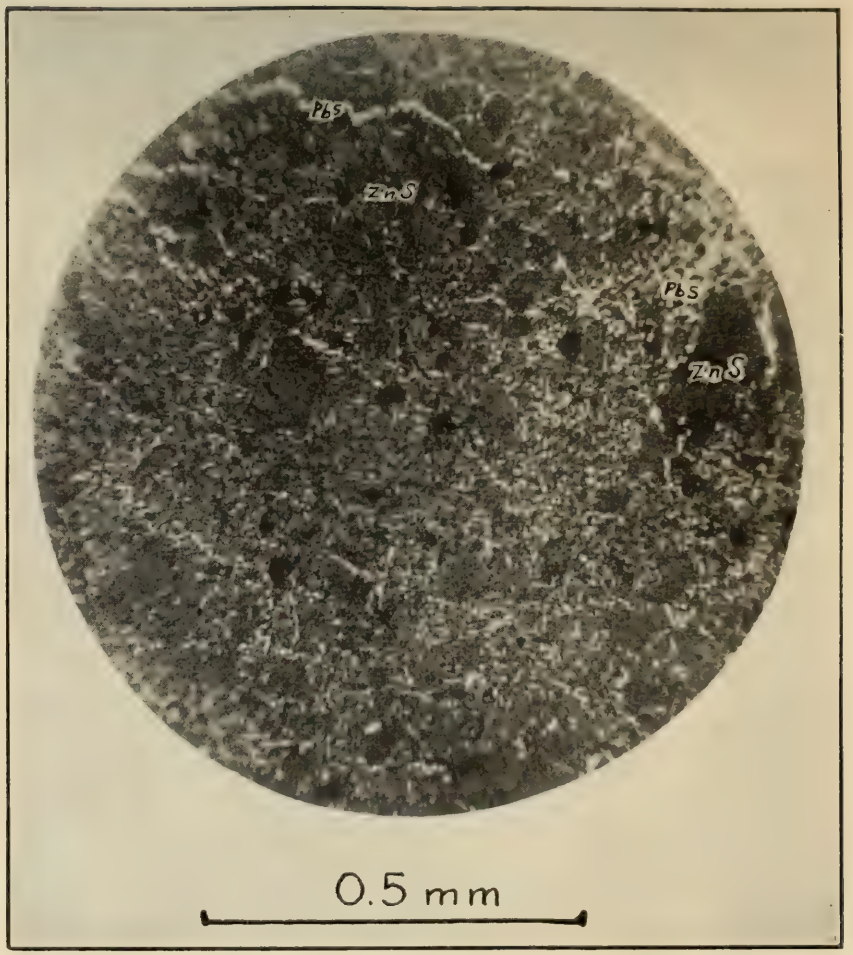
DESCRIPTION OF ORE.

The lead-zinc ore represented by No. 1 and No. 1, *A*, contained galena, sphalerite, small quantities of pyrites and chalcopyrite, included in a siderite-quartzite gangue. The lead and zinc minerals did not occur free in large pieces but were more or less finely disseminated. The sphalerite was light brown, quite different from the red and almost black varieties found in other mines of the district. Particles of supposedly clean galena often showed inclusions of quartz, sphalerite, and siderite when examined under a binocular microscope.

Polished sections of this ore, examined under the microscope, indicated that it was a typical example of one of the complex associations of lead and zinc sulphides whose separation and concentration present one of the many problems of ore treatment. A typical section of the ore is represented in the accompanying photomicrograph, Plate I, *A*. In the samples examined the lead sulphide occurred in two distinct combinations with reference to its relation to the zinc blende and the gangue. In one, represented by Plate I, *B*, a photomicrograph, the lead appeared in minute veins cutting the gangue in all directions and forming a lacelike network of mineral throughout portions of the siliceous ground mass. The galena occurring in this manner, although rather finely disseminated through the gangue, was sufficiently separated by fine grinding to be amenable to recovery by flotation, even though many of the grains were not



A. POLISHED SECTION OF ORE 1, SHOWING INTIMATE ASSOCIATION OF SPHALERITE AND GALENA.



B. POLISHED SECTION OF ORE 1, SHOWING MINUTE VEINS OF GALENA CUTTING THE GANGUE IN ALL DIRECTIONS.

entirely freed. In the other occurrence, the galena was intimately associated with sphalerite and could not be sufficiently freed by fine grinding, so that both the lead and zinc concentrates contained grains of locked sulphides of lead and zinc.

A careful study of briquettes formed of samples of the concentrates and of sealing wax indicated that where the zinc content predominated over the lead the grain went in the zinc concentrate, and, likewise, when galena formed the greater portion of the locked sulphide grain it went with the lead concentrate. It was evident that with a locked grain composed of equal proportions of the two minerals the action might be erratic, and it was reasonable to presume that such grains were as likely to go with the lead concentrate as with the zinc. Plate II, *A* (p. 24), is a photomicrograph of a grain of sphalerite in a sealing wax briquette showing included galena. Some of the minus 200-mesh material showed the same relation, and it also obtained in the lead concentrate grains containing inclusions of sphalerite.

From the observations above it is reasonable to conclude that good recoveries are possible if the ore is ground fine. It is also obvious that the zinc and lead sulphides remaining locked after fine grinding are in a class probably beyond the limits of separation by mechanical concentration.

The mill feed, represented by ore 1, contained about 7 per cent lead and from 5 to 6 per cent zinc, whereas the flotation feed from the mill, represented by ore 1*A*, contained about 5 per cent lead and 4 per cent zinc.

A chemical analysis of ore 1 or mill feed is as follows:

Chemical analysis of ore 1.

	Per cent.		Per cent.
Pb	7.4	CaO	3.1
Zn	5.8	MgO	.4
Cu	Tr.	MnO	2.3
Fe	17.3	SiO^2	30.5
S	4.5	Al^2O^3	4.2

SCREEN ANALYSIS OF ORE 1.

After the sample was crushed by a small Blake crusher to about one-fourth-inch size, a screen analysis was made in a Tyler Ro-Tap shaking machine and then the different screen products were examined to ascertain the fineness of crushing necessary for flotation testing.

The screen analysis and examination of the screen products follow:

TABLE 2.—*Screen analysis of ore 1.*

[Head[1] contained Pb, 7.4 per cent; Zn, 5.8 per cent; Fe, 17.3 per cent.]

Size of screen opening.			Weights.		Assays (per cent).			Per cent of total head content.			Cumulative per cent of total head content.		
Mesh.	Millimeters.	Inch.	Per cent.	Cumulative per cent.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
On 4	4.699	0.185	24.0	24.0	6.6	5.2	18.5	21.3	21.5	25.6	.....	.....	.....
8	2.362	.093	14.0	38.0	6.7	5.5	19.6	12.7	13.3	15.8	34.0	34.8	41.4
14	1.168	.046	26.0	64.0	7.5	6.0	18.4	26.3	26.9	27.6	60.3	61.7	69.0
20	.833	.0328	6.0	70.0	7.1	6.6	17.8	5.7	6.7	6.2	66.0	68.4	75.2
35	.417	.0164	8.8	78.8	7.7	7.0	17.4	9.2	10.5	8.8	75.2	78.9	84.0
48	.295	.0116	3.5	82.3	7.8	7.1	16.8	3.6	4.3	3.4	78.8	83.2	87.4
65	.208	.0082	2.6	84.9	8.0	7.2	16.3	2.8	3.3	2.4	81.6	86.5	89.8
100	.147	.0058	3.0	87.9	8.6	6.9	15.6	3.5	3.4	2.7	85.1	89.9	92.5
150	.104	.0041	3.0	90.9	9.7	6.3	14.8	3.9	3.3	2.5	89.0	93.2	95.0
200	.074	.0029	1.6	92.5	11.1	7.2	13.5	2.4	1.9	1.2	91.4	95.1	96.2
Through 200	.074	.0029	7.2	99.7	10.1	4.5	12.4	9.9	5.5	5.1	101.3	100.6	101.3
Loss and error by difference	.....	.....	+0.3	.....	.....	.....	.....	−1.3	−0.6	−1.3	.....	.....	.....
Total	.....	.....	100.0	.....	.....	.....	.....	100.0	100.0	100.0	.....	.....	.....

[1] This term is used to denote sample tested.

EXAMINATION OF SCREEN PRODUCTS.

Product on 4-mesh screen.—A relatively small number of particles of seemingly clean galena, sphalerite, siderite, and quartzite were visible in this screen product, but most of the mineral particles present were mechanically combined.

Product on 8-mesh screen.—The galena appeared to be finely disseminated throughout the gangue, although it was also more or less mechanically combined with the sphalerite. Very little free galena or sphalerite was noted.

Products on 14, 20, and 35 mesh screens.—These screen products were similar to those on the 8-mesh screen, except that they seemed to carry more free mineral. Particles of galena and sphalerite were still mechanically combined with each other and with gangue particles.

Product on 48-mesh screen.—Although many mineral particles were still mechanically combined, considerable free galena seemed to be present.

Product on 65-mesh screen.—The material on a screen of this size still contained a quantity of mechanically combined products, but the combined mineral particles seemed to consist principally of galena and gangue particles. More free galena and sphalerite were present than in the preceding product.

Product on 100-mesh screen.—A large proportion of the product consisted of free mineral particles. Both the galena and sphalerite appeared to be free to a large extent, although included particles were still present. The material would seem to be suitable to flotation.

Product on 150 and 200 mesh screens.—This material was similar to the product on the 100-mesh screen. Particles of included galena, sphalerite, and gangue could still be seen.

Product through 200-mesh screen.—It was difficult to ascertain the presence of combined particles of galena and sphalerite in this fine material, although there is no doubt that such particles were present, as the photomicrograph shows, (see Plate II, *A*). A few particles of galena and gangue could, however, be seen in this screen product.

As a result of the examination of the various screen products, the ore was crushed to pass a 65-mesh screen. Practically all of the ore used in testing for differential flotation was crushed to this size or finer. A screen analysis of this material for flotation testing follows:

TABLE 3.—*Screen analysis of material for flotation testing of ore 1.*

[Head contained Pb, 7.4 per cent; Zn, 5.8 per cent; Fe, 17.3 per cent.]

Size of screen opening.			Weights.		Assays (per cent).			Per cent of total head content.			Cumulative per cent of total head content.		
Mesh.	Millimeters.	Inches.	Per cent.	Cumulative per cent.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
100	0.147	0.0058	11.4	.....	6.2	6.0	17.5	9.4	11.7	11.6	.....	.....	.....
150	.104	.0041	25.0	36.4	6.1	5.9	17.8	20.5	25.5	25.7	29.9	37.0	37.3
200	.074	.0029	7.4	43.8	5.7	5.8	17.2	5.7	7.2	7.4	35.6	44.4	44.7
Through 200	.074	.0029	55.6	99.4	8.8	5.3	16.0	66.2	50.7	51.6	101.8	95.1	96.3
Loss or error by difference.	.....	.....	+0.6	.....	.....	.....	.....	−1.8	+4.9	+3.7	.....	.....	.....
Total	.....	.....	100.0	.....	.....	.....	.....	100.0	100.0	100.0	.....	.....	.....

The analysis shows that 55 per cent of the material for flotation testing passed the 200-mesh screen and that this screen product contained 66 per cent of lead and 50 per cent of zinc.

RESULTS OF FLOTATION TESTS.

The results obtained by testing this lead-zinc ore for differential flotation did not indicate as high recoveries as were obtained with the flotation feed from the mill (ore 1, *A*). The results of tests given below have been selected from a number run on this ore. All tests were run without any attempt to clean the products.

Results of test 1.

[Head contained Pb, 7.4 per cent; Zn, 5.7 per cent; Fe, 17.3 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	57.6	7.4	5.5	68.5	11.4	2.8
Zinc concentrate	8.7	22.4	16.0	21.7	72.6	17.1
Middling	3.3	4.5	19.6	4.1	7.3	10.4
Tailing	.9	.6	18.9	7.7	6.7	69.3

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Charcoal	1.0
Barrett Co. No. 2 coal-tar creosote	.4
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

Remarks.—Soda ash, charcoal, and coal-tar creosote were used for the lead concentrate, the pine oil being added to raise the zinc sulphide after the lead concentrate had been removed. The results showed a fair differential selection, especially as no attempt was made to clean the concentrates, but the recoveries of both the lead and the zinc were relatively low.

Results of test 12.

[Head contained Pb, 7.4 per cent; Zn, 5.7 per cent; Fe, 17.3 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	58.8	7.1	7.1	73.5	13.5	4.4
Zinc concentrate	4.4	26.9	15.1	7.2	67.5	12.4
Middling	1.5	5.1	23.1	1.3	6.7	10.2
Tailing	2.2	1.2	19.2	17.0	14.1	74.1

Flotation agents.

	Pounds per ton.
Soda ash	2.0
Barrett Co. No. 2 coal-tar creosote	.4
General Naval Stores Co. No. 5 s. d. pine oil	.1
Copper sulphate	.5
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

Remarks.—Of these flotation agents the first three were used to raise the lead and the last two to raise the zinc sulphide after the lead concentrate had been removed. The results indicated a fair differential selection of the two sulphides, as in test 1, but the recoveries of both lead and zinc were relatively low.

Results of test 41.

[Head contained Pb, 6.5 per cent; Zn, 5.3 per cent; Fe, 17.6 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	41.5	4.7	9.2	65.1	9.0	5.3
Zinc concentrate	7.7	25.8	14.5	18.0	74.0	12.5
Middling	5.5	7.7	21.0	4.8	8.3	6.8
Tailing	.4	.6	19.2	4.2	7.7	74.2

Flotation agents.

	Pounds per ton.
Barrett Co. (Vancouver) coal-tar creosote	1.2
General Naval Stores Co. No. 5 s. d. pine oil	.4
Copper sulphate	2.0
Water glass, 40° B	20.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.4

Remarks.—In this test the pulp was pretreated with SO_2 gas, after which the first two flotation agents were added to raise the lead sulphide. After the removal of the lead concentrate the three remaining flotation agents were added to recover the zinc blende. The results indicated a differential selection, the SO_2 gas seeming to keep the zinc mineral down although the lead tenor of the lead concentrate was a bit low. Both the lead and zinc concentrates no doubt could have been improved by passing them through cleaner cells. Several tests were run with SO_2 gas with more or less favorable results.

Results of test 42.

[Head contained Pb, 6.5 per cent; Zn, 5.3 per cent; Fe, 17.5 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	38.9	2.0	9.9	68.8	4.3	6.5
Tailing	2.3	5.4	18.6	31.3	90.1	93.4

Flotation agents.

	Pounds per ton.
Vancouver coal-tar creosote	0.6
General Naval Stores Co. No. 5 s. d. pine oil	.4

Remarks.—As in test 41, pretreatment with SO_2 gas seemed to prevent the floating of the zinc sulphide. This fact was more marked here in that the zinc content of the lead concentrate was much lower. Although the grade of product was low, the lead tenor could have been raised by further treatment in cleaner flotation cells. This was one of several tests whose object was to get a lead concentrate low in zinc, no attempt being made to recover the zinc mineral after removal of the lead concentrate. The results of using SO_2 gas seemed to indicate possibilities in effecting a separation of the lead and zinc.

Results of test 63.

[Head contained Pb, 6.5 per cent; Zn, 5.3 per cent; Fe, 17.6 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	53.4	8.7	7.1	65.7	13.1	3.2
Zinc concentrate	10.5	33.2	10.6	19.7	76.4	7.3
Middling	4.8	4.6	23.2	8.1	9.6	14.5
Tailing	.55	.03	19.5	5.8	.4	75.6

Flotation agents.

	Pounds per ton.
Soda ash	4.0
Barrett Co. Salt Lake heavy coal-tar creosote	.4
General Naval Stores Co. No. 5 s. d. pine oil	.04
Copper sulphate	1.0
Water glass, 40° B	10.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

Remarks.—The lead concentrate was obtained with the first three flotation agents, the copper sulphate and water glass being subsequently added to raise the zinc. Oil No. 350 was added after the zinc concentrate had been removed in order to produce the middling. Results indicated a fair differential selection of the sulphides. The grade of products could, no doubt, have been improved by cleaning.

TESTING ORE 1, *A*, FOR DIFFERENTIAL FLOTATION.

DESCRIPTION OF ORE.

Ore 1, *A*, was the actual flotation feed from the mill after the mill feed (ore 1) had been treated by gravity concentration. Its chemical composition was very similar to that of the mill feed, although the lead and zinc content was a trifle lower, running about 5 and 4 per cent, respectively. A chemical analysis is as follows:

Chemical analysis of ore 1, A.

	Per cent.		Per cent.
Pb	5.7	CaO	3.6
Zn	4.6	MgO	.4
Fe	17.8	MnO	2.4
Cu	Tr.	SiO_2	30.8
S	3.8	Al_2O_3	4.7

SCREEN ANALYSIS OF ORE 1, *A*.

This flotation feed was found to be more readily amenable to differential flotation than the mill feed, especially as regards higher recoveries of both lead and zinc. These relatively higher recoveries, however, were probably due, in part at least, to the flotation feed being ground wet and considerably finer than the mill feed, which

was crushed to 65-mesh size. Referring to the screen analysis of the mill feed (ore 1) given in Table 3 (*see* p. 13), it will be seen that only 55 per cent passed the 200-mesh screen, whereas the screen analysis of the flotation feed, given below, shows that 81 per cent passed through the 200-mesh screen.

TABLE 4.—*Screen analysis of flotation feed from mill, ore 1, A.*

[Head contained Pb, 5.5 per cent; Zn, 4.3 per cent; Fe, 17.5 per cent.]

Size of screen opening.			Weights.		Assays (per cent).			Per cent of total head content.			Cumulative per cent of total head content.		
Mesh.	Millimeters.	Inches.	Per cent.	Cumulative per cent.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
On 100	0.147	0.0058	1.5	.....	5.4	3.0	17.6	1.4	1.1	1.4	.....	.....	.....
150	.104	.0041	6.3	7.8	4.7	4.3	17.7	5.5	6.4	6.6	6.9	7.5	8.0
200	.074	.0029	10.7	18.5	4.3	4.0	17.1	8.2	9.9	10.6	15.1	17.4	18.6
Through 200	.074	.0029	81.0	99.5	5.5	4.5	17.1	80.9	84.9	79.1	96.0	102.3	97.7
Loss or error by difference	.....	.....	.5	.....	.....	.....	.....	+4.0	−2.3	+2.3	.....	.....	.....
Total	.....	.....	100.0	.....	.....	.....	.....	100.0	100.0	100.0	.....	.....	.....

The screen analysis shows that the material passing the 200-mesh screen contained practically 81 per cent of the total lead and 85 per cent of the total zinc.

EXAMINATION OF SCREEN PRODUCTS.

Product on 100-mesh screen.—When this screen product was examined free mineral particles could be seen, although there were also many included mineral particles, especially of galena and siderite. The principal minerals observed were galena, sphalerite, siderite, and quartz.

Products on 150 and 200 mesh screens.—These products appeared to be similar to those on the 100-mesh screens, although there seemed to be more free mineral. Galena particles combined with siderite and with quartz could still be seen.

Product through 200-mesh screen.—This product contained considerably more free mineral particles, although included mineral particles of galena and quartz were still present. Aside from the galena particles all other minerals appeared to be free.

RESULTS OF FLOTATION TESTS.

The results obtained in testing the flotation feed of ore 1, *A*, were in general better than those obtained when using the mill feed, ore 1, especially in regard to recoveries of the lead and zinc sulphides. As already stated, these relatively higher recoveries were probably

due to the fact that the material had been crushed wet and considerably finer than the mill feed and had not been permitted to dry before flotation. All products were obtained direct from a single cell without any attempt at cleaning. The results of tests given below have been selected from a number.

Results of test 12.

[Head contained Pb, 5.8 per cent; Zn, 4.6 per cent; Fe, 17.8 per cent.]

Grade of products	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	46.0	10.0	8.8	81.2	22.5	5.1
Zinc concentrate	5.9	25.4	15.7	13.0	70.8	11.3
Middling	2.5	2.8	24.2	3.2	4.6	10.2
Tailing	.4	.1	19.5	4.7	1.5	75.6

Flotation agents.

	Pounds per ton.
Soda ash	2.0
Charcoal	1.0
Barrett Co. No. 2 coal-tar creosote	.4
General Naval Stores Co. No. 5 s. d. pine oil	.1
Copper sulphate	1.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

Remarks.—The first four flotation agents were used to raise the lead, the copper sulphate and No. 350 oil being added to raise the zinc blende after the lead concentrate had been removed. Without the copper sulphate, relatively low recoveries of zinc were obtained. The grade of products could have been improved by cleaning, though the recoveries of both the lead and the zinc were fair

Results of test 14.

[Head contained Pb, 5.8 per cent; Zn, 4.6 per cent; Fe, 17.8 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	50.5	8.2	7.8	82.3	16.8	4.1
Zinc concentrate	4.1	24.2	16.5	10.5	78.6	13.8
Middling	2.0	.8	26.5	3.0	1.5	12.8
Tailing	.15	.05	19.2	1.7	.7	72.1

Flotation agents.

	Pounds per ton.
Soda ash	2.0
Charcoal	1.0
Barrett Co. No. 2 coal-tar creosote	.4
General Naval Stores Co. No. 5 s. d. pine oil	.05
Copper sulphate	1.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

Remarks.—The grade of the lead product was better than in previous tests, probably because less No. 5 pine oil was used than in test 12. The recoveries of both minerals were fairly good and the grade of zinc product could have been improved by further treatment in cleaner cells. The soda ash, charcoal, Barrett No. 2, and G. N. S. Co. No. 5 were used to raise the lead sulphide, whereas the copper sulphate and No. 350 oil were used for the zinc concentrate and middling.

Results of test 16.

[Head contained Pb, 5.8 per cent; Zn, 4.6 per cent; Fe, 17.8 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	52.1	9.3	7.5	81.2	18.3	3.8
Zinc concentrate	5.3	28.7	14.8	11.7	79.8	10.6
Middling	1.5	1.1	23.7	2.2	2.0	11.1
Tailing	.2	.2	20.0	2.4	3.0	78.0

Flotation agents.

	Pounds per ton.
Soda ash	2.0
Barrett Co. No. 2 coal-tar creosote	.4
General Naval Stores Co. No. 5 s. d. pine oil	.05
Copper sulphate	1.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

Remarks.—This test was practically the same as test 14 except that no charcoal was used. The grade of lead product was fair, and a good grade of zinc product could have been obtained by further treatment in cleaner cells. The recoveries of lead and zinc were fairly good. Comparing this test with test 14 (*see* p. 18), there did not seem to be much difference in the grade of products with or without the addition of charcoal.

Results of test 18.

[Head contained Pb, 5.8 per cent; Zn, 4.6 per cent; Fe, 17.8 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	54.7	8.1	6.5	76.7	14.3	3.0
Zinc concentrate	6.4	29.3	13.4	14.1	81.0	9.6
Middling	1.8	1.0	26.9	3.2	2.3	15.5
Tailing	.4	.1	19.2	4.7	1.5	73.5

Flotation agents.

	Pounds per ton.
Soda ash	2.0
Barrett Co. No. 2 coal-tar creosote	.4
General Naval Stores Co. No. 5 s. d. pine oil	.1
Copper sulphate	.5
Imperial fuel oil	.4
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.1

Remarks.—Both products from this test were of fairly good grade, although no attempt was made to clean them. The first three flotation agents were used to produce the lead concentrate, the copper sulphate and imperial fuel oil being added later to recover the zinc sulphide. Oil No. 350 was used only for the middling.

Results of test 32.

[Head contained Pb, 5.5 per cent; Zn, 4.3 per cent; Fe, 17.5 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	45.3	8.7	6.6	84.3	20.7	3.9
Zinc concentrate	4.8	36.7	12.5	8.1	79.0	6.6
Middling	2.2	.8	24.0	1.4	.7	4.8
Tailing	.2	.07	18.6	2.8	1.2	79.6

Flotation agents.	Pounds per ton
Potash alum	2.0
Barrett Co. No. 2 coal-tar creosote	.4
General Naval Stores Co. No. 5 s. d. pine oil	.1
Copper sulphate	.5
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

Remarks.—The results indicated a good recovery of lead and a fair grade lead product. The zinc product was of higher grade than previous tests showed, probably because of the alum in the pulp. Potash alum was used in place of the soda ash; although it seemed to give a fairly good differential selection of the sulphides, it was more expensive than other chemicals, and other alums did not produce as good results. The first three flotation agents were used to float the lead mineral and the copper sulphate, oil No. 350 being added after the lead concentrate had been removed.

Results of test 43.

[Head contained Pb, 5.5 per cent; Zn, 4.3 per cent; Fe, 17.5 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	44.6	8.2	9.0	79.5	18.7	5.0
Zinc concentrate	6.4	26.8	14.1	14.6	78.4	10.1
Tailing	.6	.1	19.6	8.5	1.8	86.9

Flotation agents.	Pounds per ton.
Soda ash	2.0
Barrett Co. No. 2 coal-tar creosote	.4
Georgia Pine & Turpentine Co. No. 194 crude turpentine	.2
Copper sulphate	.5

Remarks.—All of the flotation agents except the copper sulphate were used to raise the lead mineral. Oil No. 194 was apparently as satisfactory as the General Naval Stores Co. No. 5 oil used in other tests. The copper sulphate was the only flotation agent used to float the zinc mineral after the lead concentrate had been removed. The grade of the products was fair and could readily have been improved by treatment in cleaner cells.

Results of test 72.

[Head contained Pb, 3.4 per cent; Zn, 4.3 per cent; Fe, 17.5 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	45.8	8.0	8.2	75.7	10.6	2.7
Zinc concentrate	3.7	28.3	14.4	14.2	85.7	10.7
Middling	1.7	2.3	23.2	2.5	2.6	6.5
Tailing	.2	.08	18.3	4.5	1.4	79.8

Flotation agents.

	Pounds per ton.
Soda ash	2.0
Mixture (1 to 4) of cresylic acid and alcohol	1.0
Copper sulphate	.5
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

Remarks.—The mixture of cresylic acid and alcohol seemed to work fairly well with this ore in effecting a good lead product. The zinc concentrate was produced by the addition of the copper sulphate and 0.05 pound of No. 350 oil, the rest being used for the middling. The grade of the zinc product could, no doubt, have been improved by cleaning.

Results of test 73.

[Head contained Pb, 3.4 per cent: Zn, 4.3 per cent; Fe, 17.5 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	48.1	7.9	7.5	70.3	9.1	6.1
Zinc concentrate	5.7	38.1	10.4	16.6	88.2	5.9
Middling	2.9	2.1	26.5	6.8	3.9	12.0
Tailing	.4	.03	18.7	9.0	.5	82.4

Flotation agents.

	Pounds per ton.
Soda ash	2.0
Cresylic acid	.4
Barrett Co. No. 2 coal-tar creosote	.4
Copper sulphate	.5
General Naval Stores Co. No. 5 s. d. pine oil	.1

Remarks.—Soda ash, cresylic acid, and Barrett No. 2 oil were used to float the lead mineral. The copper sulphate was the only flotation agent added to produce the zinc concentrate after the lead concentrate had been removed, oil No. 5 being used for the middling. Both lead and zinc products were good, the zinc recovered in the zinc concentrate being especially good.

Results of test 75.

[Head contained Pb, 3.4 per cent; Zn, 4.3 per cent; Fe, 17.5 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	56.4	9.5	5.0	61.9	8.2	1.0
Lead concentrate (2)	24.3	19.1	9.4	10.0	6.2	.7
Zinc concentrate	4.4	35.2	11.3	12.7	81.2	6.4
Middling	3.8	.3	27.0	6.6	.4	9.1
Tailing	.2	.13	19.2	4.6	2.4	86.7

Flotation agents.

	Pounds per ton.
Soda ash	2.0
Mixture (1 to 4) of cresylic acid and alcohol	1.0
General Naval Stores Co. No. 5 s. d. pine oil	.2
Copper sulphate	1.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

Remarks.—Lead concentrate (2) could have been either returned to the flotation feed or re-treated separately. This test was run with 4,000 grams of ore.

Results of test 80.

[Head contained Pb, 3.4 per cent; Zn, 4.3 per cent; Fe, 17.5 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	44.0	10.7	6.1	66.7	12.8	1.8
Zinc concentrate	5.3	40.8	8.3	13.7	83.4	4.2
Middling	4.0	2.3	23.4	9.4	4.3	10.8
Tailing	.4	.1	18.4	9.2	1.8	82.6

Flotation agents.

	Pounds per ton.
Soda ash	2.0
Barrett Co. No. 2 coal-tar creosote	.4
General Naval Stores Co. No. 5 s. d. pine oil	.2
Copper carbonate	1.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

Remarks.—Soda ash, Barrett No. 2, and G. N. S. Co. No. 5 were used to float the lead mineral. After the lead concentrate was removed, copper carbonate was the only flotation agent added to produce the zinc concentrate, oil No. 350 being added for the middling. The results indicated that copper carbonate can be used in the presence of soda ash to replace copper sulphate in floating the zinc mineral.

CONCLUSIONS FROM TESTS ON ORES 1 AND 1, *A*.

On the basis of the experimental work done on ores 1 and 1, *A*, the following conclusions seem justified:

1. A complete separation of the galena and sphalerite by gravity or by differential flotation is impossible, because of the intimate association of the sulphides and their dissemination through the gangue.
2. The ore must be crushed to 100-mesh size to effect a good separation of the lead and zinc sulphide minerals.
3. Lead and zinc of good grade and satisfactory recoveries of both minerals can be obtained by differential flotation with the proper flotation mixture, especially by a roughing and cleaning system.
4. Soda ash seems to be essential in effecting a lead product of good grade with this ore.
5. A coal-tar creosote, cresylic acid, or alcohol, with possibly a small amount of some pine oil or some mixture of any of these flotation agents, seems to effect a good grade lead product in the presence of soda ash, under the proper conditions.
6. This ore seems to be amenable to treatment by the Bradford SO_2 process in effecting a separation of the lead and zinc sulphides.
7. Copper sulphate or some other copper compound, such as copper carbonate (*see* test 80, p. 22), added to the pulp containing soda ash after the lead concentrate has been removed, seems to give the best results in floating the zinc mineral.
8. Water glass seems to increase the recovery of the zinc mineral, to a small extent, at least.
9. Better results are obtained with the flotation feed than with the mill feed, especially in effecting higher recoveries of both the lead and zinc sulphides. It must be noted, however, that these higher recoveries are probably due, in part at least, to the flotation feed having been ground wet and considerably finer than the mill feed.

TESTING ORE 2 FOR DIFFERENTIAL FLOTATION.

DESCRIPTION OF ORE.

Ore 2 was another lead-zinc ore containing a relatively high percentage of zinc blende, with galena and some pyrite, in a quartz-siderite gangue. Some of the ore is more or less coarsely disseminated, indicating the possibility of gravity concentration, at least on tables, but the sulphide minerals were intimately associated in much of the ore, which would require fine grinding to liberate them from the gangue and from each other. The zinc blende, or sphalerite, was reddish brown, quite different from the zinc mineral in ore 1.

Under the microscope the lead sulphide appeared to be closely associated with quartz and occurred as inclusions disseminated through the sphalerite. The photomicrograph given as Plate III, *A*,

shows inclusions of galena in sphalerite and its occurrence along a small fissure or quartz vein in the sphalerite. Examination of a polished section of a briquette of sealing wax and flotation tailing from this ore under relatively high-power ocular and objective showed that, although the lead and zinc minerals had been largely freed or separated from each other, a number of grains of sphalerite contained inclusions of galena, as is clearly brought out in Plate II, *B*, a photomicrograph of one of these grains. This grain or mineral particle would probably pass a 150-mesh screen.

Another mineral particle of sphalerite with inclusions of galena is shown in Plate II, *C*, a photomicrograph illustrating further the impracticability of attaining a complete separation of the two minerals by crushing them to this size. Plate II, *D*, is a photomicrograph of a grain or particle of galena including a smaller particle of sphalerite. This relation is exceptional but illustrates the possibilities of mineral combination in a complex ore.

The following analysis will give some idea of the chemical composition of this ore:

Chemical analysis of ore 2.

	Per cent.		Per cent.
Pb	8.0	CaO	1.03
Zn	24.4	MgO	.25
Fe	7.0	SiO_2	30.8
Cu	Tr.	Al_2O_3	12.69
S	15.3		

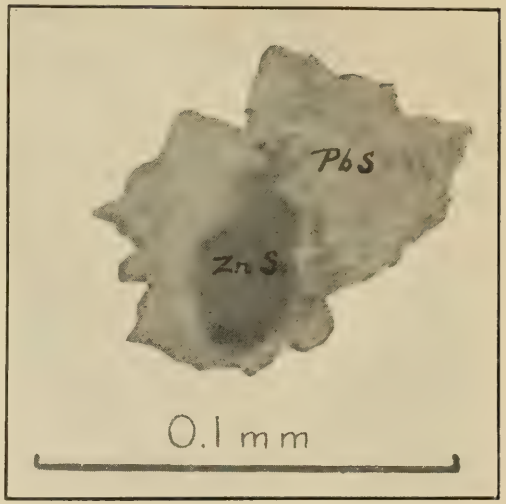
SCREEN ANALYSIS OF ORE 2.

The ore was crushed, by a small Blake crusher, to about ¼-inch size or less and a sample taken for screen analysis. The screen analysis and the results of examination of the screen products are as follows:

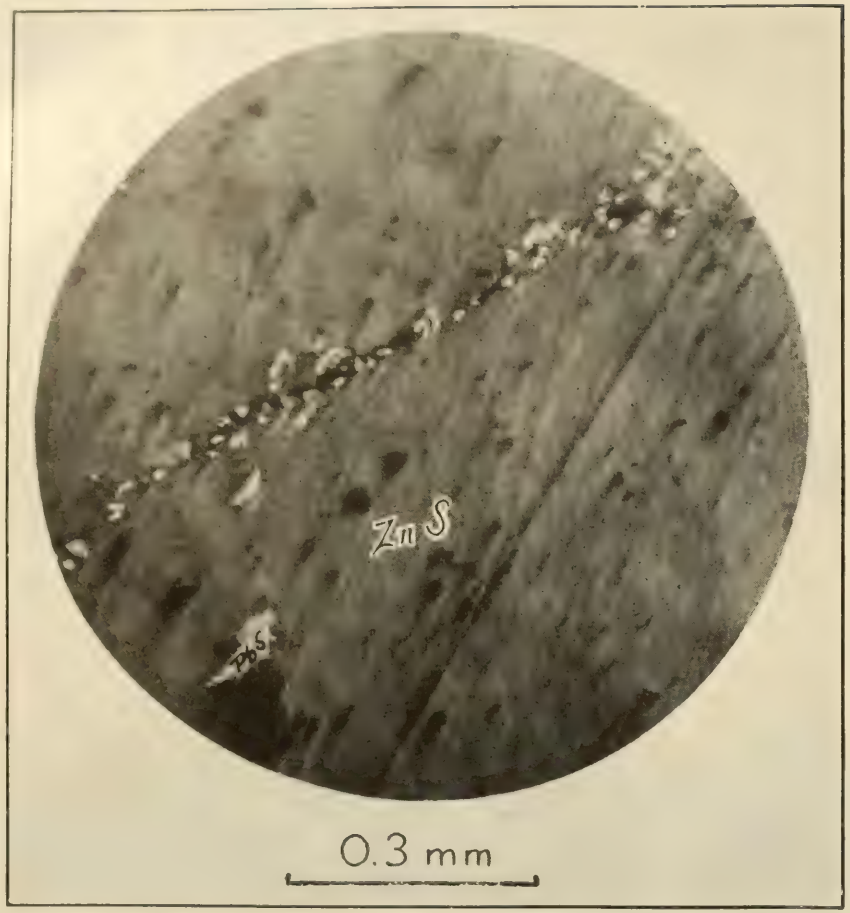
A. A GRAIN OF ORE 1, SHOWING INCLUSIONS OF GALENA IN SPHALERITE.

B. A PARTICLE OF SPHALERITE, ORE 2, WITH INCLUSIONS OF GALENA.

C. A SMALL GRAIN OF SPHALERITE, ORE 2, WITH INCLUDED GALENA.



D. SPHALERITE INCLUDED IN A SMALL GRAIN OF GALENA, ORE 2.



A. POLISHED SECTION OF ORE 2, SHOWING INCLUSIONS OF GALENA AND OCCURRENCE ALONG A SMALL FISSURE OR VEINLET IN SPHALERITE.

B. POLISHED SECTION SHOWING INTIMATE ASSOCIATION OF GALENA AND SPHALERITE IN ORE 3.

TABLE 5.—*Screen analysis of ore 2.*

[Head contained Pb, 7 per cent; Zn, 12 per cent; Fe, 6.1 per cent.]

Size of screen opening.			Weights.		Assays (per cent).			Per cent of total head content.			Cumulative per cent of total head content.		
Mesh.	Millimeters.	Inches.	Per cent.	Cumulative per cent.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
On 8	2.362	0.093	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	1.651	.065	9.0	.....	5.5	3.8	5.9	7.1	2.6	8.7	.....	.....	.....
14	1.168	.046	10.0	19.0	6.5	8.9	6.2	9.3	6.9	10.1	16.3	9.5	18.8
20	.833	.0328	12.7	31.7	6.0	11.1	6.1	10.8	10.9	12.6	27.2	20.6	31.4
28	.589	.0232	12.1	43.8	5.7	13.5	6.3	9.8	12.6	12.4	37.0	33.0	43.8
35	.417	.0164	10.5	54.3	6.1	15.7	6.6	9.1	12.8	11.3	46.1	45.8	55.1
48	.295	.0116	8.1	62.4	5.9	17.0	6.3	6.8	10.6	8.3	52.9	56.4	63.4
65	.208	.0082	6.8	69.2	6.2	17.3	6.1	6.0	9.1	6.7	58.9	65.5	70.1
100	.147	.0058	6.1	75.3	6.4	18.1	6.5	5.6	8.5	6.4	64.5	74.0	76.5
150	.104	.0041	4.8	80.1	7.0	19.8	6.4	4.8	7.3	5.1	69.3	81.3	81.6
200	.074	.0029	1.2	81.3	7.6	19.5	6.8	1.3	1.8	1.3	70.6	83.1	82.9
Through .. 200	.074	.0029	18.3	100.0	10.6	13.9	6.4	27.7	19.7	19.2	98.3	102.8	102.1
Loss or error by difference.....	.....	.....	+.4	.....	.....	.....	.....	+1.7	−2.8	−2.1	.....	.....	.....
Total.....	.....	.....	.....	.....	.....	.....	.....	100.0	100.0	100.0	.....	.....	.....

EXAMINATION OF SCREEN PRODUCTS.

Products on 8 to 20 mesh screens.—When these screen products were examined it was noted that most of the minerals appeared to be mechanically combined, although some free sphalerite could be seen. The presence of free zinc mineral was probably due to the relatively high content of sphalerite.

Product on 28-mesh screen.—This screen product contained some free zinc blende. The galena and pyrite were combined with the zinc mineral and with the gangue.

Product on 35-mesh screen.—In this product there appeared to be considerably more free sphalerite and some free quartz. Some free galena could be seen.

Products on 48 and 65 mesh screens.—Much clean zinc mineral and quartz could be seen, with some free galena, although most of the galena and pyrite were mechanically combined with the zinc and quartz or with each other.

Product on 100-mesh screen.—Most of the sphalerite and quartz appeared to be free, although a small amount of the zinc mineral was mechanically combined with galena.

Product on 150-mesh screen.—Nearly all of the minerals, such as sphalerite, galena, pyrite, and quartz, appeared to be free, although some included particles of galena and sphalerite were no doubt present, as indicated by the photomicrographs. A few particles of galena combined with pyrite could also be seen.

Products on and through 200-mesh screen.—These screen products were similar to that on the 150-mesh screen, but considerably more pyrite and some chalcopyrite seemed to be present.

Examination of these screen products indicated it would be advisable to crush or grind the material to pass a 100-mesh screen in order to liberate most of the minerals. In all the tests with this ore, therefore, it was ground so that practically all would pass a 100-mesh screen. A screen analysis of the material used for flotation is as follows:

TABLE 6.—*Screen analysis of ore 2 for flotation testing.*

[Head contained Pb, 7 per cent; Zn, 12.3 per cent; Fe, 5.6 per cent.]

Size of screen opening.			Weights.		Assays (per cent).			Per cent of total head content.			Cumulative per cent of total head content.		
Mesh.	Millimeters.	Inches.	Per cent.	Cumulative per cent.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
On 100	0.147	0.0058	5.6	.....	6.6	16.2	6.7	5.1	7.3	6.8	.....	.....	.....
150	.104	.0041	16.0	21.6	6.3	15.2	6.1	14.3	19.7	17.5	19.4	27.0	24.3
200	.074	.0029	4.2	25.8	6.3	15.3	6.2	3.7	5.2	4.6	23.1	32.2	28.9
Through .. 200	.074	.0029	73.8	99.6	7.7	11.4	5.6	81.1	68.3	73.5	104.2	100.5	102.4
Loss or error by difference	.....	.....	+.4	.....	.....	.....	.....	−4.2	−0.5	−2.4	.....	.....	.....
Total	.....	.....	100.0	.....	.....	.....	.....	100.0	100.0	100.0	.....	.....	.....

The screen analysis shows that about 75 per cent of the material crushed for flotation testing passed the 200-mesh screen and that about 80 per cent of the lead value and nearly 70 per cent of the zinc value was contained in the 200-mesh product.

RESULTS OF FLOTATION TESTS.

When this ore was tested for differential flotation obtaining a high-grade lead product, a high recovery of the lead mineral was at first difficult because of the relatively high zinc content. With the proper flotation agents, however, it was later possible to obtain fairly satisfactory results, with good-grade products and excellent recoveries of both lead and zinc. Some results of the tests included here will indicate the possibilities in the treatment of this ore by differential flotation. It is, therefore, believed that the lead and zinc minerals in this ore could be separated commercially by flotation on a large scale. The following results of the tests have been selected from a number; no attempt was made to clean the products.

Results of test 104.

[Head contained Pb, 8 per cent; Zn, 24.4 per cent; Fe, 7 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
Lead concentrate	*Per cent.* 57.4	*Per cent.* 9.0	*Per cent.* 3.0	*Per cent.* 41.3	*Per cent.* 2.1	*Per cent.* 2.5

Flotation agent.

	Pounds per ton.
Eugenol	0.13

Remarks.—Eugenol seemed to give a fair lead product, but was too expensive for commercial use. Guaiacol gives similar results and, although cheaper, is also too expensive.

Results of test 527.

[Head contained Pb, 9 per cent; Zn, 19 per cent; Fe, 7.2 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
Lead concentrate	*Per cent.* 52.5	*Per cent.* 8.7	*Per cent.* 5.6	*Per cent.* 79.3	*Per cent.* 6.2	*Per cent.* 10.6

Flotation agents.

	Pounds per ton.
Sodium phosphate	20.0
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.1
Potassium acid sulphate	20.0

Remarks.—Both the grade of the lead product and the recovery of lead were fair. The flotation agents were too expensive for commercial use, especially when in the large quantities that would be needed.

Results of test 528.

[Head contained Pb, 9 per cent; Zn, 19 per cent; Fe, 7.2 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
Lead concentrate	*Per cent.* 64.6	*Per cent.* 8.5	*Per cent.* 3.1	*Per cent.* 62.4	*Per cent.* 3.9	*Per cent.* 3.7

Flotation agents.

	Pounds per ton.
Sodium phosphate	20
Sodium thiosulphate	20

Remarks.—The lead product was of fair grade, but the recovery of lead was relatively low. The froth was thin but heavily mineralized. The cost of the flotation agents was high, but results showed a fair differential separation of the galena from the zinc blende and the possibility of flotation without oil.

Results of test 532.

[Head contained Pb, 9 per cent; Zn, 19 per cent; Fe, 7.2 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	56.3	9.2	3.8	70.7	5.5	6.0
Tailing	3.4	20.5	7.8	33.4	95.4	95.8

Flotation agents.

	Pounds per ton.
Sodium phosphate	20.0
Sodium thiosulphate	20.0
Mixture of 4 parts wood alcohol and 1 part coal-tar creosote	.5

Remarks.—Except for the addition of the oil mixture, this was run the same as test 328. As the results show, the oil mixture increased the recovery of lead but lowered the grade of the product. As in test 528, the chemical reagents were too expensive for commercial use.

Results of test 533.

[Head contained Pb, 9 per cent; Zn, 19 per cent; Fe, 7.2 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	43.2	14.9	5.0	76.8	12.5	11.1

Flotation agents.

	Pounds per ton.
Sodium phosphate	2.0
Sodium thiosulphate	2.0
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.1

Remarks.—The same chemical reagents were used as in the two preceding tests, Nos. 528 and 532, but the quantity was much less. Results indicated that the smaller quantity of the reagents permitted more zinc to be floated and therefore lowered the grade of the product. On the other hand, oil No. 400 seemed to increase the recovery of both the lead and the zinc, and its presence might counteract or modify somewhat the selective action of the reagents.

Results of test 537.

[Head contained Pb, 7 per cent; Zn, 12.9 per cent; Fe, 6.1 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	59.7	6.7	2.0	78.5	4.8	3.0

Flotation agents.

	Pounds per ton.
Sodium phosphate	10
Sodium thiosulphate	10

Remarks.—In this test the feed differed from that in previous tests, the lead and zinc content being lower. The results indicated a product of good grade and a good recovery of lead.

Results of test 554.

[Head contained Pb, 7 per cent; Zn, 12.9 per cent; Fe, 6.1 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	42.2	8.0	4.8	66.4	68.0	8.6
Zinc concentrate	7.3	34.7	9.6	31.0	80.0	46.7
Tailing	.8	2.9	4.9	6.7	13.1	47.0

Flotation agents.

	Pounds per ton.
Water glass (40° B.)	10.0
Barrett No. 2 coal-tar creosote	.2
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.1
Sulphuric acid	5.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.4

Remarks.—The grade of both concentrates was fair, considering that they were rougher products. Cleaning would probably improve the grade considerably. The recovery of lead was somewhat low but the zinc recovery fairly good. Undoubtedly the quantities of flotation agents could be reduced in practice. The water glass and Barrett No. 2 oil were used to float the lead; the other flotation agents, the zinc.

Results of test 563.

[Head contained Pb, 7 per cent; Zn, 12.9 per cent; Fe, 6.1 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	47.5	9.3	4.0	76.0	8.1	7.4
Zinc concentrate	5.0	37.3	7.7	21.6	87.3	38.1
Middling	2.7	8.4	8.0	2.3	3.9	8.0
Tailing	.5	.3	5.4	3.7	1.2	46.3

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Barrett Co. No. 2 coal-tar creosote	.4
Water glass (40° B.)	10.0
Copper sulphate	2.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.4

Remarks.—The recoveries of both lead and zinc were better than in the preceding test, No. 554. The grades of the rougher products could have been improved by cleaning. Soda ash and oil No. 2 were employed to float the lead, the other flotation agents being added after the lead concentrate had been removed.

Results of test 566.

[Head contained Pb, 7 per cent; Zn, 12.9 per cent; Fe, 6.1 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	53.5	5.1	6.3	76.7	3.9	10.3
Zinc concentrate	4.6	40.2	8.5	17.7	84.1	37.6
Middling	1.9	5.7	8.5	3.2	5.2	16.4
Tailing	.2	1.4	4.7	1.4	5.5	39.0

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Water glass (40° B.)	20.0
Barrett Co. No. 2 coal-tar creosote	.4
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.1
Copper sulphate	1.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

Remarks.—The grade of products and recoveries was good. The soda ash, Barrett No. 2 oil, Pensacola Tar & Turpentine Co. No. 400, and half of the quantity of water glass given above were used to float the lead sulphide, the remainder being added to float the zinc mineral after the lead concentrate had been removed. The quantities of the flotation agents would have to be cut down in practice.

Results of test 567.

[Head contained Pb, 7 per cent; Zn, 12.9 per cent; Fe, 6.1 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	59.3	6.5	3.9	72.9	4.3	5.5
Zinc concentrate	4.8	39.2	8.5	20.3	90.1	41.2
Middling	.7	1.4	9.3	1.1	1.2	16.8
Tailing	1.2	.2	4.3	8.7	.8	35.7

Flotation agents.

	Pounds per ton.
Soda ash	10.0
Barrett Co. No. 2 coal-tar creosote	1.0
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.1
Copper sulphate	1.0
Water glass (40° B.)	10.0
General Naval Stores Co. No. 5 s. d. pine oil	.1
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.2

A. POLISHED SECTION SHOWING INCLUSIONS OF GALENA IN SPHALERITE, ORE 3.

B. A 48-MESH PARTICLE OF ORE 3, SHOWING ASSOCIATION OF GALENA AND SPHALERITE.

A. A 65-MESH PARTICLE OF ORE 3, SHOWING ASSOCIATION OF THE GALENA AND ZINC BLENDE.

B. GALENA DISSEMINATED IN A SMALL GRAIN OF ZINC BLENDE, ORE 3.

C. GALENA IN A SMALLER PARTICLE OF ZINC BLENDE, ORE 3.

Remarks.—The grade of products and the zinc recovery were good, but a better grade could have been obtained readily by cleaning. The soda ash and oils No. 2 and No. 400 were used to float the galena, the other flotation agents being added to float the zinc.

TESTING ORE 3 FOR DIFFERENTIAL FLOTATION.

DESCRIPTION OF ORE.

Ore 3 was a lead-zinc ore containing galena and sphalerite, with a little pyrite, in a quartzite-siderite gangue. The lead and zinc minerals were quite intimately associated and rather finely disseminated throughout the gangue. The zinc blende was reddish-brown, similar in color to that in ore 2.

Examination of polished sections under the microscope showed an association of galena and sphalerite typical of the occurrence of these two minerals in the complex ores of lead and zinc. The interlocking grains, shown in the photomicrograph, Plate III, *B* (p. 25), were so small and the distribution of the lead and zinc so uniform that their complete separation by crushing would be very difficult and often practically impossible. The photomicrograph, Plate IV, *A*, shows galena in fractures and interstices in the sphalerite.

Examination of the grains of lead and zinc sulphides in a briquette of sealing wax and crushed ore showed that although much of the galena and sphalerite had been freed or separated by the crushing, an appreciable amount of the intimately associated galena and sphalerite had not been separated by this treatment. Plates IV and V illustrate clearly the intimate association of the minerals in the briquetted crushed sulphides. Plates IV, *B*, and V, *A*, photomicrographs of 48 and 65 mesh particles, show the close association of the galena and zinc blende. Plate V, *B*, a photomicrograph of a grain of zinc blende of probably the maximum size that would pass through a 100-mesh screen, shows clearly to what extent the disseminated galena occurs in the crushed material. Another sample of the same ore examined after crushing to pass a 100-mesh screen revealed the same conditions as described above. The included galena in the blende is shown in Plate V, *C*, a photomicrograph of the same magnification as Plate V, *B*, but of a grain of considerably smaller size.

This ore contained relatively high values in zinc, as clearly indicated by the following chemical analyses of three different lots:

Chemical analyses of ore 3.

Constituents.	Lot 1.	Lot 2.	Lot 3.
	Per cent.	*Per cent.*	*Per cent.*
Pb	4.91	9.56	4.54
Zn	18.68	13.94	19.26
Fe	5.04	4.35	4.35
Cu	Tr.	Tr.	Tr.
S	10.41	9.28	11.11
CaO	1.67	9.9	3.49
MgO	.92	.37	3.43
SiO_2	47.74	44.03	47.27
Al_2O_3	9.96	8.27	9.65

SCREEN ANALYSIS OF ORE NO. 3.

A screen analysis was made of a sample of this ore after going through a Blake crusher and a set of rolls, the coarsest particles being about one-fourth inch in diameter. The screen products were examined to ascertain the size to which it would be necessary to crush the ore for flotation testing. The screen analysis and examination of the screen products follow:

TABLE 7.—*Screen analysis of ore 3.*

[Head contained Pb, 5.8 per cent; Zn, 11.1 per cent; Fe, 4.3 per cent.]

Size of screen opening.			Weights.		Assays (per cent).			Per cent of total head content.			Cumulative per cent of total head content.		
Mesh.	Millimeters.	Inches.	Per cent.	Cumulative per cent.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
On 4	4.699	0.185	13.0	.....	2.5	6.6	4.7	5.5	7.7	14.2	.....	.....	.....
8	2.362	.093	18.2	31.2	4.1	6.8	4.3	12.9	11.2	18.1	18.4	18.9	32.3
10	1.651	.065	9.2	40.4	4.9	10.1	4.7	7.7	8.4	10.0	26.1	27.3	42.3
14	1.168	.046	7.7	48.1	5.4	12.8	4.6	7.2	8.8	8.1	33.3	36.1	50.4
20	.833	.0328	6.5	54.6	5.7	14.0	4.4	6.4	8.2	6.7	39.7	44.3	57.1
28	.589	.0232	5.9	60.5	5.9	14.6	4.7	6.0	7.7	6.5	45.7	52.0	63.6
35	.417	.0164	5.0	65.5	5.7	15.6	4.5	4.8	7.1	5.1	50.5	59.1	68.7
48	.295	.0116	4.2	69.7	6.3	15.9	4.5	4.5	6.0	4.4	55.0	65.1	73.1
65	.208	.0082	4.7	74.4	7.2	17.2	4.8	5.9	7.3	5.1	60.9	72.4	78.2
100	.147	.0058	4.1	78.5	7.2	16.2	5.1	5.2	5.9	4.9	66.1	78.3	83.1
150	.104	.0041	5.4	83.9	7.7	15.7	4.5	7.2	7.6	5.6	73.3	85.9	88.7
200	.074	.0029	2.6	86.5	9.0	15.5	4.5	4.0	3.6	2.8	77.3	89.5	91.5
Through 200	.074	.0029	13.2	99.7	9.8	13.1	4.0	22.2	15.5	12.3	99.5	105.0	103.8
Loss and error by difference	.....	.....	+0.3	.....	.....	.....	.....	+0.5	−5.0	−3.8	.....	.....	.....
Total	.....	.....	100.0	.....	.....	.....	.....	100.0	100.0	100.0	.....	.....	.....

EXAMINATION OF SCREEN PRODUCTS.

Products on 4 to 28 mesh screens.—Under the microscope much combined galena, sphalerite, siderite, and quartz were visible. Sphalerite was the predominating mineral, although little could be found free from the associated minerals.

Product on 35-mesh screens.—This product contained free particles of galena, sphalerite, and quartz, but the greater percentage of galena and a comparatively large quantity of sphalerite were mechanically combined either with other minerals or with each other. The gangue appeared to be combined with galena and siderite rather than with the sphalerite.

Products on 48 and 65 mesh screens.—These products were similar to the material on a 35-mesh screen.

Products on 100-mesh screen.—This material contained a considerable proportion of free particles of galena, sphalerite, and quartz, although mechanically combined particles of these minerals could still be seen under the microscope. Most of this material would be suitable for flotation.

Products on 150, 200, and through 200 mesh screens.—Most of the mineral particles were free, but some of the quartz and siderite particles still contained included galena. It was, of course, difficult to determine particles of sphalerite containing included galena except by the microscope of higher power used in making the photomicrographs.

It was decided to crush the ore to pass a 65-mesh screen, so that practically all of the ore used in testing for differential flotation was crushed to this size or finer. A screen analysis of this crushed material is as follows:

TABLE 8.—*Screen analysis of ore 3 for flotation testing.*

[Head contained Pb, 5.7 per cent; Zn, 11 per cent; Fe, 4.4 per cent.]

Size of screen opening.			Weights.		Assays (per cent).			Per cent of total head content.			Cumulative per cent of total head content.		
Mesh.	Millimeters.	Inches.	Per cent.	Cumulative per cent.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
On 65	0.208	0.0082	5.0	.....	3.2	11.2	3.9	2.8	5.1	4.5	.....	.....	.....
100	.147	.0058	14.6	19.6	4.0	11.7	3.5	10.2	15.6	11.6	13.0	20.7	16.1
150	.104	.0041	20.4	40.0	4.7	11.7	3.4	16.8	21.7	15.7	29.8	42.4	31.8
200	.074	.0029	15.8	55.8	5.3	11.5	3.9	14.7	16.6	14.1	44.5	59.0	45.9
Through 200	.074	.0029	43.8	99.6	6.9	10.2	5.0	53.0	40.6	49.8	97.5	99.6	95.7
Loss and error by difference	.....	.....	+0.4	.....	.....	.....	.....	+2.5	+0.4	+4.3	.....	.....	.....
Total	.....	.....	100.0	.....	.....	.....	.....	100.0	100.0	100.0	.....	.....	.....

RESULTS OF FLOTATION TESTS.

The following tests were selected from a number and indicate the possibilities of making commercial products by differential flotation. All tests were run without any attempt to clean the products.

Results of test 192.

[Head contained Pb, 4.9 per cent; Zn, 18.7 per cent; Fe, 5 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	59.4	14.5	2.5	65.0	4.2	2.8
Zinc concentrate (1)	7.3	45.2	6.9	24.8	52.4	30.0
Zinc concentrate (2)	2.6	37.4	7.2	8.7	33.5	23.8
Tailing	.3	.4	4.4	3.3	1.2	48.0

Flotation agents.

	Pounds per ton.
Barrett Co. No. 2 coal-tar creosote	0.3
Georgia Pine & Turpentine Co. No. 208 wood creosote oil	.1
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.4
Sulphuric acid	2.0

Remarks.—For the lead concentrate 0.3 pound of Barrett No. 2 oil and 0.1 pound of Pensacola Tar & Turpentine Co. oil No. 400 were used. The remaining flotation agents were added to float the zinc mineral. The grade of products and the recoveries were good, especially the zinc concentrates. The two zinc concentrates combined gave a product containing 4.3 per cent lead and 41.7 per cent zinc with a recovery of 85 per cent of the zinc.

Results of test 212.

[Head contained Pb, 4.7 per cent; Zn, 17 9 per cent; Fe, 4.8 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	63.1	9.9	2.6	71.2	2.9	2.9

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Charcoal	1.0
Barrett Co. (Vancouver) light coal-tar creosote	.4

Remarks.—In this test, as in many others, the lead concentrate was the only product saved, in order to eliminate many chemical analyses when the ore was tested with different coal-tar creosotes or, when a series of tests was run, to avoid changing the quantity, make, or grade of the flotation oil. The lead product was fairly good in view of the relatively high zinc content of the head sample. The recovery of lead was fair.

Results of test 213.

[Head contained Pb, 4.7 per cent; Zn, 17.9 per cent; Fe, 4.8 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
Lead concentrate	*Per cent.* 58.2	*Per cent.* 12.2	*Per cent.* 2.2	*Per cent.* 80.5	*Per cent.* 4.4	*Per cent.* 2.9

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Charcoal	1.0
Barrett Co. (Vancouver) heavy coal-tar creosote	.4

Remarks.—As compared with the results of test No. 212, the heavy coal-tar creosote seemed to give a higher recovery but raised more zinc, causing a product of somewhat lower grade.

Results of test 224.

[Head contained Pb, 4.7 per cent; Zn, 17.9 per cent; Fe, 4.8 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
Lead concentrate	*Per cent.* 56.0	*Per cent.* 12.5	*Per cent.* 2.8	*Per cent.* 71.4	*Per cent.* 4.2	*Per cent.* 3.5

Flotation agents.

	Pounds per ton.
Borax	5.0
Charcoal	1.0
Barrett Co. No. 4 coal-tar creosote	.4

Remarks.—In this test borax was used in place of soda ash. In such tests borax did not seem to give better results than the ash.

Results of test 239.

[Head contained Pb, 6 per cent; Zn, 10.6 per cent; Fe, 3.9 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
Lead concentrate	*Per cent.* 54.4	*Per cent.* 11.4	*Per cent.* 2.6	*Per cent.* 68.0	*Per cent.* 8.0	*Per cent.* 4.9

Flotation agents.

	Pounds per ton.
Soda ash	5
Charcoal	1
Wood alcohol	2

Remarks.—Alcohol seemed to give fairly good results with ore 3 when substituted for a flotation oil, such as a coal-tar creosote, to raise the lead mineral.

Results of test 382.

[Head contained Pb. 5.7 per cent; Zn, 10.8 per cent; Fe, 4.4 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	53.1	11.2	3.7	50.9	5.7	4.6
Zinc concentrate	8.2	32.3	7.1	41.6	86.0	46.7
Middling	3.1	5.2	5.6	1.4	1.2	3.3
Tailing	.3	.9	3.0	3.3	5.3	43.0

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Barrett Co. No. 2 coal-tar creosote	.4
Sodium hydroxide	2.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.4
Imperial fuel oil	.2
Copper sulphate	1.0

Remarks.—For the lead concentrate the soda ash and Barrett No. 2 creosote were used. The zinc concentrate was produced by adding the sodium hydroxide, oil No. 350, and Imperial fuel oil. After the lead and zinc concentrates were removed, copper sulphate was added for the middling. The recovery of zinc in the zinc concentrate was good. The grade of product could have been improved by cleaning.

Results of test 385.

[Head contained Pb, 5.7 per cent; Zn, 10.8 per cent; Fe, 4:4 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	50.8	10.5	4.2	61.1	6.6	6.6
Zinc concentrate	7.8	42.5	6.1	30.7	88.2	31.1
Middling	3.1	10.3	7.8	2.7	4.8	8.9
Tailing	.2	.8	3.4	2.3	4.7	49.6

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Mixture (1:16) of G. N. S. Co. No. 5 pine oil and carbolic creosote	.4
Water glass (40° B.)	10.0
Copper sulphate	1.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.4
Imperial fuel oil	.2

Remarks.—The soda ash and mixture were used to raise the lead mineral. For the zinc concentrate 5 pounds of water glass, 0.5 pound of copper sulphate, 0.2 pound of No. 350 oil, and 0.1 pound of fuel oil were used, the remainder being added for the middling after the zinc concentrate had been removed. The grade of products and the recoveries, especially of zinc, were fairly good. Better products could have been made by roughing and cleaning.

Results of test 390.

[Head contained Pb, 5.8 per cent; Zn, 11.1 per cent; Fe, 4.3 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	55.9	8.9	3.2	50.1	4.2	3.8
Zinc concentrate	10.7	40.7	6.0	44.3	88.0	33.5
Middling	5.8	11.2	7.4	4.6	4.6	7.9
Tailing	.2	.3	3.8	2.3	1.8	58.7

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Charcoal	1.0
Barrett Co. No. 2 coal-tar creosote	.4
Water glass (40° B.)	5.0
Copper sulphate	.5
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.4
Imperial fuel oil	.2

Remarks.—Soda ash, charcoal, and Barrett No. 2 creosote were used for the lead concentrate. The other flotation agents were added for the zinc concentrate and middling after the lead concentrate had been removed. The grade of products was fair but could have been improved by further treatment in cleaning cells. The recovery of zinc in the zinc concentrate was good.

Results of test 392.

[Head contained Pb, 5.8 per cent; Zn, 11.1 per cent; Fe, 4.3 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	50.6	10.8	3.7	59.3	6.6	5.9
Zinc concentrate	8.0	38.7	6.9	28.7	72.5	33.4
Middling	2.9	14.8	9.2	5.2	13.5	21.6
Tailing	.4	1.1	2.5	4.2	6.0	35.2

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Barrett Co. No. 2 coal-tar creosote	.4
Wood alcohol	1.6
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.4
Imperial fuel oil	.2

Remarks.—Barrett No. 2 creosote and alcohol were used to produce the lead concentrate, soda ash and the other flotation agents being employed for the zinc concentrate and middling. It will be noticed that the zinc recovery was much lower than in other tests where copper sulphate or water glass or both were used. For rougher concentrates, however, the grade of the products was fair.

Results of test 396.

[Head contained Pb, 5.8 per cent; Zn, 11.1 per cent; Fe, 4.3 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	50.7	14.9	4.5	76.9	11.8	9.2
Zinc concentrate	3.5	32.2	8.0	17.9	86.1	55.2
Middling	2.6	11.8	4.4	2.2	5.2	5.6
Tailing	.2	.13	2.5	1.9	.6	32.8

Flotation agents.

	Pounds per ton.
Sulphuric acid	3.7
Soda ash	10.6
Barrett Co. No. 2 coal-tar creosote	.4
Copper sulphate	.5
Water glass (40° B.)	5.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.6

Remarks.—Sulphuric acid was agitated with the pulp before other agents were added, in order to brighten the mineral faces, and thus possibly increase the lead recovery. After this preagitation the soda ash and Barrett No. 2 creosote were added for the lead concentrate. For the zinc concentrate 0.5 pound of copper sulphate and 0.3 pound of No. 350 oil were added, and for the middling, the water glass and 0.3 pound of No. 350 oil. The sulphuric acid seemed to increase the recovery of lead, but also permitted more zinc in the lead concentrate. However, from these two products high-grade concentrates of both lead and zinc could, no doubt, have been made by cleaning, with good recoveries of both minerals.

TESTING ORE 4 FOR DIFFERENTIAL FLOTATION.

DESCRIPTION OF ORE.

Ore 4 contained sphalerite, galena, and some pyrite in a gangue composed chiefly of quartzite and schist. The sulphides were quite intimately associated with each other, as was clearly seen on examining polished section under the microscope.

Plate VI, *A*, is a photomicrograph of a polished section in which sphalerite is the chief constituent, the lead content in the form of galena being relatively small. Galena occurs as inclusions in the sphalerite in grains and minute particles ranging in size from those easily detected under the microscope at low magnification to specks which are only resolved by higher power. Plate VI, *A*, also shows how the galena is disseminated through the zinc blende and indicates the relative size of the galena particles, many of which are invisible at this magnification. In another specimen of this ore the galena and sphalerite seemed to occur in somewhat larger areas, and were associated as interlocking grains of varying sizes. The inclusions of galena in the sphalerite are readily distinguished in Plate VI, *B*.

A. POLISHED SECTION OF ORE 4, SHOWING GRAINS AND MINUTE PARTICLES OF GALENA IN SPHALERITE.

B. POLISHED SECTION OF ORE 4, SHOWING INTERLOCKING OF LARGER GRAINS OF SPHALERITE AND GALENA.

Making, by differential flotation, a high recovery of lead without floating a relatively large proportion of the zinc sulphide proved difficult. As the analysis below shows, the zinc content was only about 3 to 4 per cent and the lead about 11 to 12 per cent, so that even though a relatively good grade of lead concentrate was obtained, the quantity of zinc sulphide floated with the lead represented 30 to 40 per cent of the zinc in the ore. It is not difficult to obtain a high recovery of lead in a product assaying 50 to 55 per cent lead with 6 to 8 per cent zinc, but the recovery of zinc will be 30 to 40 per cent. In testing this ore, therefore, the object was to recover as much lead as possible in the lead concentrate while keeping the zinc down to a minimum.

Chemical analysis of ore 4.

	Per cent.		Per cent.
Pb	11.40	CaO	0.84
Zn	3.90	MgO	.20
Fe	11.71	SiO_2	44.54
Cu	Tr.	Al_2O_3	22.53
S	4.76		

SCREEN ANALYSIS OF ORE 4.

A screen analysis was made of a sample of this ore that had been crushed by a Blake crusher and a set of rolls so that the coarsest particle was about one-fourth inch in diameter. A set of Tyler standard screen sieves was used and the various screen products were examined to ascertain the size to which it would be necessary to crush the ore for flotation The screen analysis and the examination of the screen products follow.

TABLE 9.—*Screen analysis of ore 4.*

[Head contained Pb, 11.4 per cent; Zn, 3.9 per cent; Fe, 11.7 per cent.]

Size of screen opening.			Weights.		Assays (per cent).			Per cent of total head content.			Cumulative per cent of total head content.		
Mesh.	Millimeters.	Inch.	Per cent.	Cumulative per cent.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
On 4	4.699	0.185	29.9	.....	10.8	3.0	12.7	28.3	23.0	32.4	.....	.....	.....
8	2.362	.093	18.9	48.8	9.8	3.5	11.6	16.2	16.9	18.7	44.5	39.9	51.1
10	1.651	.065	6.6	55.4	8.9	3.8	12.2	5.1	6.5	6.9	49.6	46.4	58.0
14	1.168	.046	7.1	62.5	8.8	4.0	12.7	5.5	7.3	7.7	55.1	53.7	65.7
20	.833	.0325	6.2	68.7	8.6	4.3	11.6	4.7	6.9	6.2	59.8	60.6	71.9
28	.589	.0232	4.9	73.6	9.1	4.0	11.0	3.9	5.0	4.6	63.7	65.6	76.5
35	.417	.0164	4.1	77.7	8.4	4.3	11.8	3.1	4.6	4.2	66.8	70.2	80.7
48	.295	.0116	2.9	80.6	7.8	4.5	10.6	2.0	3.3	2.6	68.8	73.5	83.3
65	.208	.0082	2.6	83.2	10.1	4.6	11.4	2.3	3.0	2.5	71.1	76.5	85.8
100	.147	.0058	2.7	85.9	11.5	4.3	12.5	2.7	2.9	2.9	73.8	79.4	88.7
150	.104	.0041	2.2	88.1	13.0	4.4	8.2	2.5	2.4	1.5	76.3	81.8	90.2
200	.074	.0029	1.3	89.4	14.5	4.1	7.9	1.7	1.4	.9	78.0	83.2	91.1
Through 200	.074	.0029	10.3	99.7	20.3	4.5	8.5	18.4	11.9	7.5	96.4	95.1	98.6
Loss and error by difference	.....	.....	+0.3	.....	.....	.....	.....	+3.6	+4.9	+1.3	.....	.....	.....
Total	.....	.....	.....	100.0	.....	.....	.....	100.0	100.0	100.0	.....	.....	.....

EXAMINATION OF SCREEN PRODUCTS.

Products on 4 to 28 mesh screens.—Much mechanically combined galena, sphalerite, and gangue could be seen under the microscope. Although there was some free mineral, most of the minerals were combined with each other. Galena predominated over sphalerite and relatively more galena than any of the other minerals present seemed to be free.

Products on 35 and 48 mesh screens.—Some galena and some sphalerite were free, but a large proportion of the minerals appeared to be mechanically combined.

Products on 65-mesh screen.—This screen product contained relatively more free galena and free sphalerite than the coarser products but most of the pyrite appeared to be combined with the gangue.

Product on 100-mesh screen.—A much greater proportion of the galena and sphalerite particles appeared to be free, although gangue particles combined with other minerals could be seen under the microscope. This size of screen product might prove satisfactory for flotation, but finer crushing would permit a better separation of the minerals by flotation and a more satisfactory recovery.

Product on 150-mesh screen.—This material contained principally free galena, sphalerite, pyrite, and quartz, although a few particles of quartz showed inclusions of lead and zinc, and particles of pyrite combined with zinc could be seen. As most of the mineral particles appeared to be free, it was decided to crush the ore to this size for flotation.

Products on 200 and through 200 mesh screens.—Most of the mineral particles in this material were free, although some of the quartz particles still showed inclusions of the sulphides. Because of the difficulty of determining particles of sphalerite containing inclusions of galena, except with the higher power microscope used in making photomicrographs, it is probable that a small proportion of the zinc particles still contained inclusions of galena.

After examination of the screen products it was thought best to crush this ore to pass a 100-mesh screen, so that practically all of the ore used in testing for differential flotation was crushed to this size or finer. A screen analysis of the material used for flotation follows.

TABLE 10.—*Screen analysis of ore 4 for flotation testing.*

[Head contained Pb, 11.4 per cent; Zn, 3.9 per cent; Fe, 11.7 per cent.]

Size of screen opening.			Weights.		Assays (per cent).			Per cent of total head content.			Cumulative per cent of total head content.		
Mesh.	Millimeters.	Inches.	Per cent.	Cumulative per cent.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
On.....100	0.147	0.0058	4.4	.....	6.9	2.9	10.6	2.6	3.1	3.9	.....	.....	.....
150	.104	.0041	14.0	18.4	8.1	3.1	11.4	10.0	11.3	13.7	12.6	14.4	17.6
200	.074	.0029	9.8	28.2	9.8	3.2	11.4	8.4	8.2	9.6	21.0	22.6	27.2
Through....200	.074	.0029	71.6	99.8	12.5	4.0	11.7	78.6	73.3	71.6	99.6	95.9	98.8
Loss and error by difference.	.....	.....	+0.2	.....	.....	.....	.....	+0.4	+4.1	+1.2	.....	.....	.....
Total.....	.....	.....	100.0	.....	.....	.....	.....	100.0	100.0	100.0	.....	.....	.....

RESULTS OF FLOTATION TESTS.

Many flotation oils and chemicals were used in tests of this ore for differential flotation, some of which have given promising results in effecting a good grade of lead product low in zinc. Charcoal in combination with soda ash and coal-tar creosote has seemed to give a better lead product than some of the other mixtures, but results in a somewhat lower recovery of lead. However, it is probable that better recoveries could be obtained in practice than are indicated by the results given below.

Results of test 155.

[Head contained Pb, 11.4 per cent; Zn, 3.9 per cent; Fe, 11.7 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate.....	52.6	4.7	4.9	66.4	17.4	7.3

Flotation agents.

	Pounds per ton.
Mixture (2:1) of wood alcohol and a distillate taken off from a mixture of (1:1) of coal-tar creosote and wood alcohol at 82° to 120° C.....	2.5

Remarks.—The grade of the product was fair, especially with regard to the zinc content of the lead concentrate, but the recovery of lead was relatively low.

Results of test 180.

[Head contained Pb, 11.4 per cent; Zn, 3.9 per cent; Fe, 11.7 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate.....	59.1	6.3	5.6	69.5	21.6	6.4

Flotation agents.

	Pounds per ton.
Mixture (4:1) of wood alcohol and a distillate taken off from a mixture (1:1) of coal-tar creosote and alcohol at 80° C	1
Sodium hydroxide	1

Remarks.—The grade of product was fair, but the recovery of lead was comparatively low. The sodium hydroxide seemed to effect a somewhat higher recovery.

Results of test 185.

[Head contained Pb, 11.4 per cent; Zn, 3.9 per cent; Fe, 11.7 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	55.8	7.2	5.7	76.4	29.0	7.6

Flotation agents.

	Pounds per ton.
Sodium hydroxide	1.0
General Naval Stores Co. No. 20 coal-tar creosote	.5

Remarks.—This product contained more zinc than the product of the preceding test, but the recovery of lead was higher; the grade may be considered good, especially as it was a rougher product and could no doubt have been improved by cleaning.

Results of test 207.

[Head contained Pb, 11.4 per cent; Zn, 3.9 per cent; Fe, 11.7 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	56.9	4.9	4.9	77.4	19.5	6.5

Flotation agents.

	Pounds per ton.
Sodium hydroxide	1
Mixture (4:1) of wood alcohol and Flotation Oil & Chemical Co. No. 21 coal-tar creosote	1

Remarks.—Both the grade of product and the lead recovery were fairly good.

Results of test 572.

[Head contained Pb, 10.4 per cent; Zn, 3.4 per cent; Fe, 11.5 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	54.7	9.1	6.9	87.8	43.6	8.7

Flotation agents.

	Pounds per ton.
Sodium hydroxide	1
Mixture (4:1) of wood alcohol and Flotation Oil & Chemical Co. No. 21 coal-tar creosote	1

Remarks.—The grade of the product was fair; the lead recovery was good, but the zinc content was relatively high. The higher recovery of lead was undoubtedly due to sample having been crushed wet. To compare wet and dry crushing see the preceding test, No. 207.

Results of test 585.

[Head contained Pb, 8.8 per cent; Zn, 3.5 per cent; Fe, 12 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent*
Lead concentrate	51.4	6.4	5.3	73.6	23.0	5.6

Flotation agent.

	Pounds per ton.
Soda ash	20

Remarks.—The grade of product was fair, but the recovery of lead was relatively low. The quantity of the flotation agent was too large for commercial use but it could probably be reduced in practice.

Results of test 792.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe, 11.5 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	56.5	6.1	6.3	81.2	33.2	9.5
Middling	12.0	9.2	16.6	17.8	51.8	26.0
Tailing	1.0	.6	12.3	5.3	12.1	69.0

Flotation agents.

	Pounds per ton.
Soda ash	20.0
Flotation Oil & Chemical Co. No. 21 coal-tar creosote	.2
Pensacola Tar & Turpentine Co. No. 400 wood creosote	.1
Copper sulphate	2.0
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.4

Remarks.—Both the grade of product and the lead recovery were fairly good. The middling product could have been treated in separate flotation cells. The quantity of soda ash used would have to be reduced in practice. The copper sulphate and oil No. 350 were added after the lead concentrate had been removed.

Results of test 795.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe, 11.5 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	59.4	7.4	5.5	77.1	36.3	7.3

Flotation agents.

	Pounds per ton.
Mixture (1:4) of Barrett Co. No. 633 coal tar creosote and wood alcohol	2
Sodium hydroxide	1

Remarks.—The grade of product and the recovery of lead were only fair.

Results of test 828.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe, 11.5 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	54.9	6.9	6.1	72.6	34.5	8.5
Middling (1)	31.4	11.3	12.8	8.8	11.9	3.8
Middling (2)	14.9	10.7	15.0	13.5	36.8	14.3

Flotation agents.

	Pounds. per ton.
Soda ash	2.5
General Naval Stores Co. No. 22 coal-tar creosote	.25
Pensacola Tar & Turpentine Co. No. 350 crude wood pine oil	.25

Remarks.—The grade of product was fair, but the recovery of lead was low. This test was run with 4,000 grams of ore.

Results of test 841.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe, 11.5 per cent.]

Grade of products.	Assay of products.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	51.9	8.5	7.6	79.4	49.1	12.2
Middling (1)	14.9	9.0	13.0	4.9	11.1	4.5
Middling (2)	7.3	4.8	15.0	4.4	11.1	9.6

Flotation agents.

	Pounds. per ton.
Soda ash	2.5
Sodium hydroxide	1.0
Mixture (1:4) of Flotation Oil & Chemical Co. coal tar creosote No. 21 and wood alcohol	2.0
General Naval Stores Co. No. 5 s. d. pine oil	.1

Remarks.—Soda ash, sodium hydroxide, and 1 pound per ton of mixture were used for the lead concentrate, and the remaining flotation agents for the middling products. The lead concentrate contained too much zinc, but the product might have been improved by further treatment in cleaner cells or by tabling. The low zinc content of the lead made difficult the effecting of a good lead recovery without recovery of a large proportion of the zinc in the lead concentrate.

Results of test 863.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe, 11.5 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
Lead concentrate	*Per cent.* 39.2	*Per cent.* 5.4	*Per cent.* 9.0	*Per cent.* 56.7	*Per cent.* 29.5	*Per cent.* 13.7

Flotation agents.

	Pounds per ton.
Gasoline	0.3
Flotation Oil & Chemical Co. No. 21 coal-tar creosote	.4
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.2

Remarks.—Gasoline seemed to keep down the zinc in the lead concentrate, but the grade of the latter was very low. If a high lead recovery could have been obtained with this mixture and the rougher product had been put through cleaner cells, a good-grade product low in zinc might have been possible.

Results of test 867.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe, 11.5 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
Lead concentrate	*Per cent.* 41.9	*Per cent.* 6.1	*Per cent.* 7.6	*Per cent.* 55.4	*Per cent.* 30.5	*Per cent.* 10.6

Flotation agents.

	Pounds per ton.
Gasoline	4.8
Flotation Oil & Chemical Co. No. 21 coal-tar creosote	.4
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.2

Remarks.—The relatively large quantity of gasoline did not seem to improve the grade of the product or to increase the lead recovery. The zinc content of the lead concentrates was also higher in this test than in that preceding (No. 863).

Results of test 869.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe. 11.5 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
Lead concentrate	*Per cent.* 56.4	*Per cent.* 5.2	*Per cent.* 6.4	*Per cent.* 68.5	*Per cent.* 23.9	*Per cent.* 8.2

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Gasoline	1.2
Flotation Oil & Chemical Co. No. 21 coal-tar creosote	.4
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.2

Remarks.—Comparison of this test with Nos. 863 and 867 shows that the addition of soda ash improved both the grade of product and the recovery of lead, although the latter is still low.

Results of test 877.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe, 11.5 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	60.9	4.2	5.4	75.4	19.7	7.0

Flotation agents.

	Pounds per ton.
Soda ash	4.0
Charcoal	.5
Flotation Oil & Chemical Co. No. 21 coal-tar creosote	.4

Remarks.—The use of charcoal and soda ash seemed to improve the grade of the product. The recovery of lead, however, was only fair.

Results of test 890.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe, 11.5 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	60.0	4.8	5.9	74.9	22.6	7.7

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Charcoal	1.0
Wood alcohol	1.0
Flotation Oil & Chemical Co. No. 21 coal-tar creosote	.4

Remarks.—The addition of wood alcohol did not seem to improve the grade of product or to increase the recovery. Compare with test No. 877.

Results of test 892.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe, 11.5 per cent.

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lead concentrate	55.5	5.6	6.6	77.1	29.4	9.7

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Charcoal	1.0
Cresylic acid	.4
Flotation Oil & Chemical Co. No. 21 coal-tar creosote	.4

Remarks.—The addition of cresylic acid in place of wood alcohol seemed to increase the recovery somewhat, but the grade of product was not quite so good, there being more zinc in the lead concentrate.

Results of test 893.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe, 11.5 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
Lead concentrate	*Per cent.* 59.7	*Per cent.* 6.0	*Per cent.* 5.7	*Per cent.* 72.5	*Per cent.* 27.6	*Per cent.* 7.3

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Charcoal	1.0
Wood alcohol	1.0
Cresylic acid	.2

Remarks.—This test was run without oil No. 21, a coal-tar creosote, and the results indicate that the lead recovery was lower than in other tests in which that oil was used.

Results of test 894.

[Head contained Pb, 12.1 per cent; Zn, 3.2 per cent; Fe, 11.5 per cent.]

Grade of product.	Assay of product.			Recoveries.		
	Pb.	Zn.	Fe.	Pb.	Zn.	Fe.
Lead concentrate	*Per cent.* 57.3	*Per cent.* 5.7	*Per cent.* 5.2	*Per cent.* 76.7	*Per cent.* 28.8	*Per cent.* 7.3

Flotation agents.

	Pounds per ton.
Soda ash	5.0
Charcoal	1.0
Alcohol	1.0
Cresylic acid	.2
Flotation Oil & Chemical Co. No. 21 coal-tar creosote	.4

Remarks.—With the coal-tar creosote, oil No. 21, the recovery seems somewhat higher than in tests where it was not added to the flotation mixture. Wood alcohol had very little effect, if any, on the flotation of this ore.

GENERAL CONCLUSIONS.

On the basis of the experimental work the following conclusions seem justified, so far as Coeur d'Alene lead-zinc ores are concerned:

1. A complete separation of the lead and zinc sulphides by differential flotation is impossible, owing to the intimate association of the minerals, as shown by the accompanying photomicrographs.

2. Fine grinding is essential to liberate most of the sulphide minerals and to permit their separation by differential flotation.

3. A better recovery is possible with an ore that has been crushed wet than with one that has been crushed dry.

4. A pulp density of about $2\frac{1}{2}$:1 to $3\frac{1}{2}$:1 (water to solids) seems to give the best differential selection and mineral recovery at normal temperature.

5. Each ore seems to require a somewhat different flotative mixture and the effect of a certain oil or chemical on one ore may differ from that on another similar ore.

6. Differential flotation effects a more satisfactory separation of the sulphide minerals than has been obtained by existing methods.

7. A better differential selection of the lead from the zinc sulphide is effected with an alkaline or neutral pulp than with an acid pulp.

8. The quantity of the chemical or flotation agents used in the small scale tests can be reduced in large scale tests or in practice.

9. Soda ash, sodium hydroxide, sodium silicate (water glass), salt, lime, coal-tar creosote, alcohol, gasoline, and charcoal seem to assist in the selective separation and recovery of lead sulphide in the presence of zinc and iron sulphides. Their effectiveness, however, may be modified by the gangue constituents of the ore.

10. Copper sulphate or some other copper compound, such as copper carbonate, when added to a pulp containing soda ash after the lead concentrate has been removed, seems to give good results in floating the zinc mineral in some of the Coeur d'Alene lead-zinc ores.

11. The Bradford SO_2 process seems to be adaptable to the separation of the lead and zinc sulphides of some of the lead-zinc ores of Coeur d'Alene district.

12. Certain Coeur d'Alene lead-zinc ores should be amenable to differential flotation, and it should be possible to obtain good-grade lead and zinc products with the proper flotation mixture under the proper conditions, especially by a roughing and cleaning system, as well as good recoveries of both minerals.

PART II.—TESTS OF TWO COPPER ORES AND ONE ANTIMONIAL SILVER ORE FOR FLOTATION.

By Clarence A. Wright, James T. Norton, and James C. Parmelee.

INTRODUCTION.

This part of the present bulletin deals with the flotation of three Idaho ores other than the lead and zinc ores of the Coeur d'Alene district. The ores tested for flotation were a chalcopyrite-pyrrhotite copper ore from Latah County; an antimonial silver ore, the silver mineral being principally polybasite, from a property near Florence, in Idaho County; and a copper ore containing gold and silver, which is being mined near Winchester, in Lewis County. The tests included in the pages following are not to be considered as final information on the flotation of these ores, but they indicate, and may suggest, possibilities in the treatment of these or similar ores by flotation.

TESTS OF A CHALCOPYRITE-PYRRHOTITE COPPER ORE.

DESCRIPTION OF ORE.

The copper contained in this ore was in the form of chalcopyrite intimately associated with pyrrhotite and pyrite in a schistose gangue composed chiefly of muscovite, calcite, quartz, and hornblende. The chalcopyrite was both coarsely and finely disseminated. Close examination showed that some of the pieces of chalcopyrite contained grains of interlocked pyrrhotite and pyrite, which indicate the necessity of fine grinding in order to liberate the chalcopyrite from the other sulphide minerals. Examination of the screen products from a screen analysis of the crushed ore showed that the material passing the 200-mesh screen still contained some chalcopyrite mechanically combined with pyrrhotite and pyrite.

A microscopic study[2] of polished surfaces of this ore developed some interesting facts in the association of chalcopyrite and pyrrhotite. In addition to occurrences of the normal chalcopyrite and pyrrhotite, which were readily identified by differences in color and character of surface there were many areas in which the texture presented a marked difference from that of either of these two minerals. These areas had an exceedingly pitted or spongelike surface which did not polish readily, but retained its peculiar appearance long after a good surface had been obtained on the normal chalcopyrite and pyrrhotite. Polishing for a considerable time finally produced a surface of sufficient flatness to render examination possible and disclosed that these rough areas were what might be termed "cupriferous pyrrhotite,"

[2] Study and photomicrographs by R. E. Head, U. S. Bureau of Mines, Salt Lake City, Utah.

as they consisted of varying amounts of chalcopyrite and pyrrhotite, the chalcopyrite occurring as a replacement mineral filling the pits and cracks in the pyrrhotite, the roughened appearance persisting until the replacement was nearly complete. These semireplaced areas of pyrrhotite were of considerable size and the association of the minerals was so intimate and complex that separation by fine crushing would have been physically impossible, even the finest grains comprising both pyrrhotite and chalcopyrite. The application of differential flotation to the normal unaltered pyrrhotite and chalcopyrite was, no doubt, responsible for the separations obtained, and it was evident that the difficulty of effecting better separations lay in the material of complex association and variable composition. Careful study of these replacement areas showed that they comprised mixtures of the two minerals in all proportions, ranging from slightly altered pyrrhotite containing but little copper sulphide to a mixture in which chalcopyrite predominated. The latter would, in all probability, separate out with the true chalcopyrite, whereas those grains in which pyrrhotite was the chief constituent would remain with the normal pyrrhotite.

The accompanying photomicrographs are included to bring out the intimate association of the chalcopyrite and pyrrhotite. In Plate VII, *A*, the lower half represents the normal chalcopyrite, and the upper half, being composed largely of cupriferous pyrrhotite, shows the roughened, finely pitted appearance of the partly replaced pyrrhotite. These roughened areas represent the mixtures of the two sulphides which would not be separated by fine crushing.

Plate VII, *B*, is a photomicrograph of a polished section showing the relation of the normal sulphides, the lower half of the area being chalcopyrite and the upper pyrrhotite.

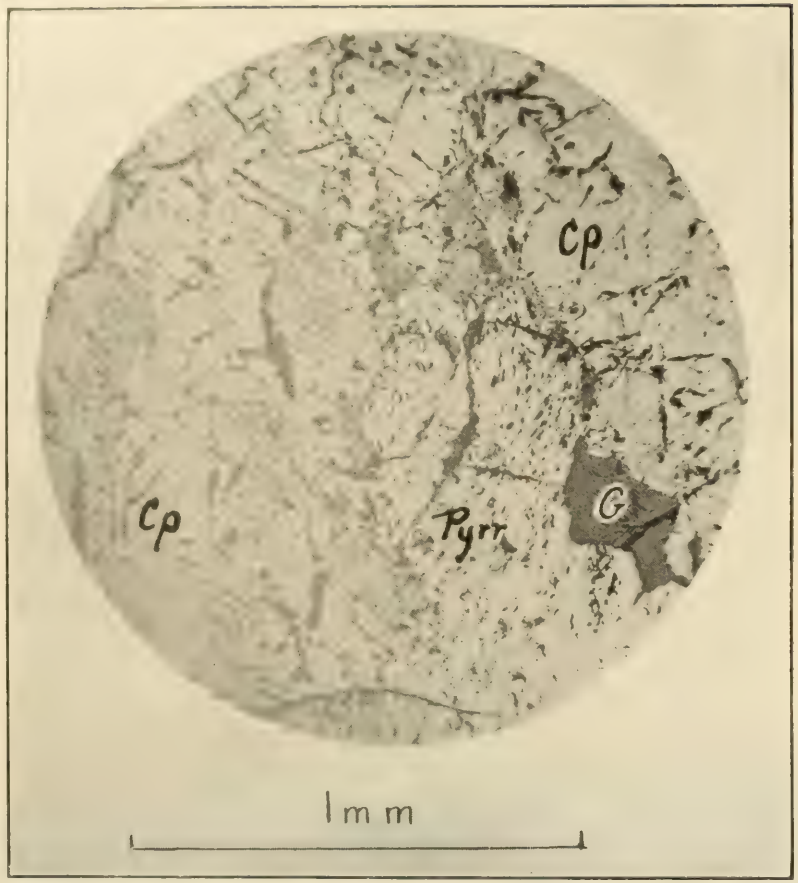
The left half of Plate VIII, *A*, shows chalcopyrite that has almost completely replaced the pyrrhotite, although remains of the latter mineral are still visible, as indicated by the pitted areas. Extending through the center of the section shown is an area of unreplaced pyrrhotite, which is bordered on the extreme right by chalcopyrite. The darker mineral in the lower right portion is quartz. These photomicrographs were taken at low magnifications and the complex relations of the minerals appear to represent appreciable areas in the ore.

Owing to the similarity in color of pyrrhotite and chalcopyrite, it is difficult to show in a photomicrograph a marked difference between the minerals. Therefore no attempt was made to photograph the crushed material.

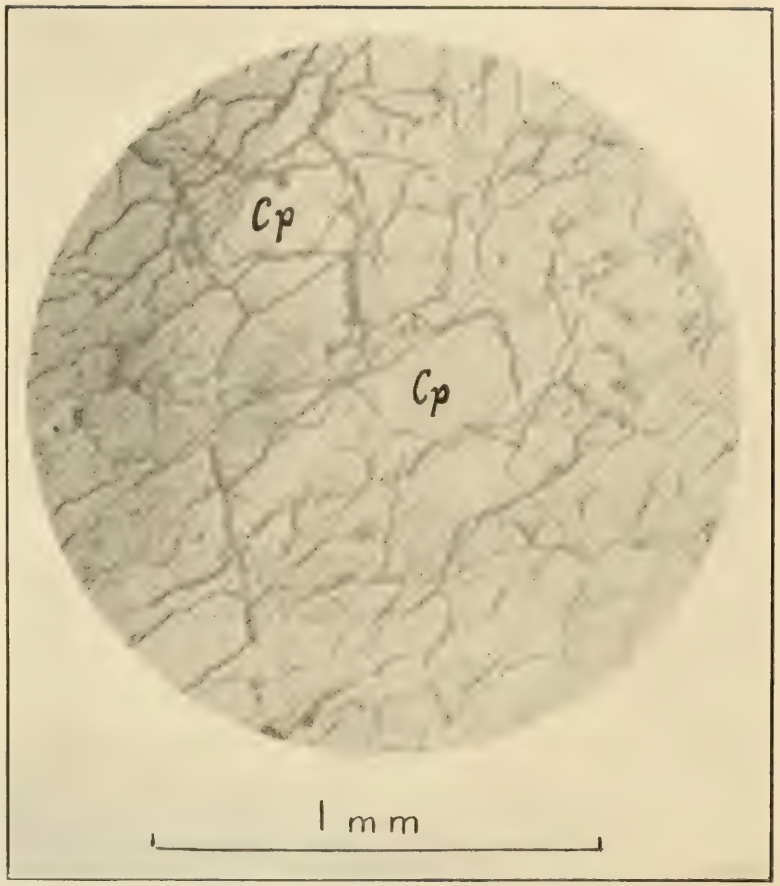
A. POLISHED SECTION SHOWING NORMAL CHALCOPYRITE (LOWER HALF) AND CUPRIFEROUS PYRRHOTITE.

Note finely fitted aspect of partly replaced pyrrhotite.

B. POLISHED SECTION SHOWING RELATION OF NORMAL SULPHIDES.



A. POLISHED SECTION SHOWING CHALCOPYRITE (AT LEFT) THAT HAS ALMOST COMPLETELY REPLACED PYRRHOTITE, REMAINS OF THE LATTER BEING INDICATED BY PITTED AREAS.



B. POLISHED SECTION SHOWING ASSOCIATION OF CHALCOCITE AND CHALCOPYRITE, THE DARKER CHALCOCITE OCCURRING IN FRACTURES AND VEINLETS IN THE CHALCOPYRITE.

SCREEN ANALYSIS.

After the sample had been crushed, by a small Blake crusher, to about one-fourth-inch size, a screen analysis was made in a Tyler Ro-Tap shaking machine, and then the various screen products were examined to ascertain the fineness of crushing that would be necessary for flotation testing. Results of the screen analysis and the examination of the screen products follow:

TABLE 11.—*Screen analysis of chalcopyrite-pyrrhotite ore.*

Size of screen opening.			Weights.		
Mesh.	Millimeters.	Inches.	Grams.	Weight (per cent).	Cumulative weight (per cent).
On.....10	1.651	0.065	573	57.3	.....
14	1.163	.046	51	5.1	62.4
20	.833	.0328	38	3.8	66.2
35	.417	.0164	78	7.8	74.0
65	.208	.0082	74	7.4	81.4
100	.147	.0058	52	5.2	86.6
150	.104	.0041	34	3.4	90.0
200	.074	.0029	15	1.5	91.5
Through 200	.074	.0029	84	8.4	99.9
Loss.....	.....	.....	1	.1	100.0
Total...	.....	.....	1,000	100.0	.....

EXAMINATION OF THE SCREEN PRODUCTS.

Product on 10-mesh screen.—The chief minerals observed were chalcopyrite, pyrrhotite, pyrite, calcite, and quartz, with minor amounts of mica and hornblende. Free chalcopyrite could be seen but a large proportion was mechanically combined with the gangue or other sulphide minerals.

Products on 14 and 20 mesh screens.—More of the chalcopyrite had been liberated than in the previous screen product, but it was still largely combined with the pyrrhotite.

Products on 35 and 65 mesh screens.—Considerably more chalcopyrite, calcite, and other minerals had been liberated. The chalcopyrite and pyrrhotite and possibly pyrite seemed to be much more intimately combined than the other minerals.

Product on 100-mesh screen.—Most of the various minerals appeared to be free, but it was difficult to determine definitely to what extent the chalcopyrite was still combined with the other sulphides.

Products on 150, 200, and through 200 mesh screens.—To all appearances, practically all the minerals had been liberated, but the same difficulty arose in distinguishing the particles of chalcopyrite combined with pyrrhotite.

From the examination of these screen products, crushing through a 65-mesh screen, at least, would seem necessary for this ore. In all the flotation tests following, therefore, practically all of the ore has been crushed through such a screen. A screen analysis of this material for flotation testing is as follows:

TABLE 12.—*Screen analysis of material for flotation testing.*

[Head contained Cu, 4.7 per cent; Fe, 15.3 per cent; S, 10.7 per cent.]

Size of screen opening.			Weights.		Assays (per cent).			Percentage of total head content.			Cumulative per cent of total head content.		
Mesh.	Millimeters.	Inches.	Weight (per cent).	Cumulative (per cent).	Cu.	Fe.	S.	Cu.	Fe.	S.	Cu.	Fe.	S.
On 65	0.208	0.0082	2.0	.....	1.1	14.7	6.6	0.5	1.9	1.2	.....	.....	.....
100	.147	.0058	14.0	16.0	4.5	16.6	11.2	13.4	15.2	14.7	13.9	17.1	15.9
150	.104	.0041	27.2	43.2	4.5	16.4	10.7	26.0	29.1	27.2	39.9	46.2	43.1
200	.074	.0029	7.2	50.4	4.2	15.0	10.3	6.4	7.1	6.9	46.3	53.3	50.0
Through..200	.074	.0029	49.2	99.6	4.5	15.5	10.6	47.1	49.8	48.7	93.4	103.1	98.7
Loss or error by difference	.....	.....	+.4	.....	.....	.....	.....	+6.6	−3.1	+1.3	.....	.....	.....
Total...	.....	.....	100.0	.....	.....	.....	.....	100.0	100.0	100.0	.....	.....	.....

Remarks.—It is interesting to note, as shown by the figures under "Percentage of total head content," that the distribution of copper and iron in the different screen products was practically the same.

When the screen products from the analysis of the crushed ore through a 65-mesh screen were examined the material on the 100-mesh screen showed much free mineral adaptable to flotation. A certain amount of combined chalcopyrite and pyrrhotite, however, could be observed. The material on the 150-mesh screen, as far as could be seen through a low-power microscope, comprised practically free mineral particles, although a few combined particles of chalcopyrite and quartz were noted. Owing to the intimate association of the chalcopyrite and pyrrhotite, there was no doubt, a small percentage of interlocked particles of these two minerals which could have been resolved with a microscope of higher power. This statement also applies to the material on and through a 200-mesh screen.

RESULTS OF FLOTATION TESTS.

When this ore was tested for differential flotation mechanical agitation machines of the Federal-Varley type (*see* fig. 1, p. 9) were used. All preliminary or small-scale tests were run in a small machine capable of treating 1,000 grams of ore. When satisfactory results were obtained with this machine the tests were repeated under the same conditions in a machine of the same type with a capacity of 4,000 grams.

Several oils and chemicals were used testing the ore for differential flotation. Certain mixtures gave good recoveries but relatively low-grade products, whereas other mixtures gave much better products, effecting a good differential separation of the chalcopyrite from the pyrrhotite, but relatively low recoveries. In testing out different mixtures or varying the quantity of a certain mixture to be used, all other conditions were kept constant. After the flotation agent was added the ore was given a preagitation for three to five minutes at a pulp dilution of 1 to 1, water to solids. Following the preagitation, water was added to raise the water level in the flotation machine so that the pulp dilution was about 3 to 1, water to solids. Agitation was then continued for 10 minutes, the froth being removed as it formed. In some tests a middling was taken off after the concentrate had been removed, more oil or flotation mixture being used to effect a higher recovery. The results from a few of the more satisfactory tests of this ore are given below:

Results of test 15.

[Head contained Cu, 4.7 per cent; Fe, 15.3 per cent.]

Grade of products.	Assay of products.		Recoveries.	
	Cu.	Fe.	Cu.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Concentrate	24.6	31.4	76.3	30.0
Middling (1)	5.9	45.3	17.0	40.2
Middling (2)	1.6	32.7	2.8	16.9
Tailing	.1	3.5	1.3	14.8

Flotation agents.

	Pounds per ton.
Soda ash	5.0
General Naval Stores Co. No. 5 pine oil	.4
Standard Chemical Co. No. 2 coal-tar creosote	.2

Remarks.—The differential separation of the chalcopyrite from pyrrhotite and pyrite was fairly good, but the recovery of copper was only fair. The grade of product was good in view of the fact that no attempt was made to clean the first product.

Results of test 22.

[Head contained Cu, 4.7 per cent; Fe, 15.3 per cent.]

Grade of products.	Assay of products.		Recoveries.	
	Cu.	Fe.	Cu.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Concentrate	26.0	37.0	83.0	34.0
Middling	1.2	4.6	3.8	44.4
Tailing	.8	6.3	11.9	28.6

Flotation agents.

	Pounds per ton.
Sodium hydroxide	2.0
Mixture (1:4) of Vancouver heavy coal-tar and alcohol	1.0
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.2

Remarks.—The figures from this test indicated a higher recovery of copper than in the preceding test, No. 15, but the iron content in the concentrate was a trifle higher. The product, on the whole, however, was fairly good.

Results of test 31.

[Head contained Cu, 4.7 per cent; Fe, 15.3 per cent.]

Grade of products.	Assay of products.		Recoveries.	
	Cu.	Fe.	Cu.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Concentrate	25.6	31.5	80.2	30.0
Middling	4.6	38.4	13.0	33.2
Tailing	.6	7.7	9.1	36.2

Flotation agents.

	Pounds per ton.
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	0.32
Barrett Co. No. 2 coal-tar creosote	1.4

Remarks.—The results indicated a product of good grade and a fair recovery of copper.

Results of test 38.

[Head contained Cu, 4.7 per cent; Fe, 15.3 per cent.]

Grade of products.	Assay of products.		Recoveries.	
	Cu.	Fe.	Cu.	Fe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Concentrate	16.3	39.8	82.9	62.5
Middling	4.5	33.3	8.2	18.5
Tailing	.5	5.5	7.1	24.0

Flotation agents used.

	Pounds per ton.
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	0.2
Barrett Co. No. 2 coal-tar creosote	.35

Remarks.—The results indicated a fair recovery of copper, but the iron content in the concentrate was relatively high.

CONCLUSIONS.

On the basis of the experimental work on this ore, the following conclusions seem justified:

1. Because of the intimate association of the chalcopyrite and pyrrhotite in the ore, a complete separation of the two minerals by gravity or differential flotation is impossible.

2. Crushing the ore to at least 65-mesh size is essential to effect a good separation of the sulphite minerals by differential flotation.

3. A good-grade copper concentrate and a fair recovery of copper can be effected by differential flotation with the proper flotation mixture; such a concentrate would assay about 20 per cent copper and about 30 to 35 per cent iron.

TESTS OF AN ANTIMONIAL SILVER ORE.

DESCRIPTION OF THE ORE.

The silver in this ore was in the form of polybasite, a sulphide of antimony and silver, which was finely disseminated throughout a hard, massive, quartz gangue. The identification of the polybasite was based upon a study[3] of its physical properties under the microscope and blowpipe tests of carefully picked material. The results of a qualitative chemical test of a sample of this ore showed only a trace of arsenic, but a comparatively large proportion of antimony. The ore also contained a small amount of argentite, but no cerargyrite or other silver mineral was noted.

Besides the argentite and polybasite, small amounts of pyrite, stibnite, and magnetite were identified, but these minerals represented only a small percentage of the metallic content of the ore. A general assay of a sample of the ore resulted as follows:

Assay of ore with reference to silver content.

Gold (ounces per ton)	0.04
Silver (ounces per ton.)	81.4
Iron (per cent)	1.13
Sulphur (per cent)	.15
Insoluble (per cent)	97.6

CRUSHING THE ORE FOR FLOTATION TESTING.

The sample of ore received for testing purposes was crushed, by a small Blake crusher, to about ¼-inch size and then screened. Most of the mineral particles seemed to be free in the material passing a 65-mesh screen, and it was therefore decided to crush the ore to that fineness for flotation testing.

A close examination of the various sizes obtained by screening the several products from flotation tests indicated that the sulphide minerals were practically freed from the gangue by the crushing, and although the tails showed quartz grains that carried inclusions of sulphides, the mineral value thus lost would be comparatively negligible when calculated on a percentage basis. Some sulphide grains

[3] Microscopic examination of this ore was made by R. E. Head, U. S. Bureau of Mines, Salt Lake City, Utah.

in the tailings were perfectly free from the gangue and under the microscope exhibited no physical characteristics that would hinder their floating. It is therefore assumed that they were carried out mechanically by the gangue.

RESULTS OF FLOTATION TESTS.

In testing this ore for flotation the same procedure was followed as in testing the chalcopyrite-pyrrhotite copper ore.

At first considerable difficulty was encountered in trying to effect a high recovery of the silver by flotation. It was thought that some of the silver might be in the form of a chloride, but examination of the tailings from tests showed that some of the polybasite mineral had partly oxidized or tarnished on the surface, preventing or interfering with their flotation. This impediment was overcome to a considerable extent by giving the ore or pulp a preliminary treatment with sodium sulphide, which brightened the mineral particles, and the newly formed sulphide coating on their surfaces permitted the particles to float, which incidentally increased the silver recovery.

Several oils and chemicals were used in testing this ore. Certain mixtures gave fair recoveries with relatively low-grade products, whereas other mixtures gave good-grade products with somewhat lower recoveries. Adding a small amount of sodium cyanide to the flotation mixture seemed to make the grade of the silver product higher, both with and without presulphidization of the ore pulp. In testing different mixtures, or varying the quantity of a certain mixture, all other conditions were kept constant. After the flotative agent was added the ore was given a preagitation for three to five minutes at a pulp dilution of 1 to 1, water to solids; then the preagitation water was added to raise the water level in the flotation machine, making the pulp dilution about 3 to 1, water to solids. Agitation was continued for 10 minutes, the froth being removed as it formed.

In tests where the ore received a sulphidizing treatment previous to flotation, the ore or pulp of about 1:1 density, water to solids, was placed in a bottle with a certain amount of sodium sulphide and the bottle agitated on rollers for any length of time desired. Then the sulphidized pulp was washed into the agitating cell of the flotation machine and floated in the usual manner.

Results of test 7.

[Head contained Au, 0.04 ounce per ton; Ag, 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.3	941.5	48.7	75.2
Tailing	Tr.	16.6	.....	19.0

Flotation agents.	Pounds per ton.
Spencer Co. residual kelp oil	0.2
Vancouver imperial fuel oil	1.0

Remarks.—The results indicated that a good grade of silver product is possible, but the recovery of silver was rather low.

Results of test 9.

[Head contained Au, 0.04 ounce per ton; Ag, 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.1	582.7	30.0	82.3
Tailing	Tr.	19.4	.....	20.9

Flotation agent.	Pounds per ton.
Turpentine-rosin mixture (5:1)	0.6

Remarks.—Results showed a rather low grade of silver product and a fair recovery. The mixture of turpentine and rosin was a strong frothing agent.

Results of test 22.

[Head contained Au, 0.04 ounce per ton; Ag, 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.4	1,235.8	47.5	73.0
Tailing	Tr.	24.4	.....	28.5

Flotation agents.	Pounds per ton.
Sodium cyanide	0.5
Cleveland Cliffs No. 2 wood creosote	1.0
Standard Chemical Co. No. 3 coal-tar creosote	.6

Remarks.—The results showed a good grade of silver product, but a rather low recovery. The addition of a small amount of sodium cyanide to the flotation mixture seemed to improve the grade.

Results of test 26.

[Head contained Au, 0.04 ounce per ton; Ag, 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.15	496.5	50.0	81.8
Tailing	Tr.	14.5	.....	15.3

Flotation agents.	Pounds per ton.
Sodium sulphide (1 hour)	0.5
Cleveland Cliffs No. 2 wood creosote	2.0
Standard Chemical Co. No. 3 coal-tar creosote	.6

Remarks.—The results indicated that a sulphidizing treatment of the ore previous to flotation increased the silver recovery.

Results of test 30.

[Head contained Au, 0.04 ounce per ton; Ag, 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.2	507.8	67.5	83.0
Tailing	Tr.	13.0	.....	13.9

Flotation agents.	Pounds per ton.
Sodium sulphide (1 hour)	1.0
Cleveland Cliffs Co. No. 2 wood creosote	1.4
Standard Chemical Co. No. 3 coal-tar creosote	.6

Remarks.—By doubling the amount of sodium sulphide used in the preceding test, No. 26, the recovery was increased a trifle. The grade of the product was about the same.

Results of test 37.

[Head contained Au, 0.04 ounce per ton; Ag, 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.2	601.8	57.5	85.0
Tailing	Tr.	13.4	.....	14.5

Flotation agents.	Pounds per ton.
Sodium sulphide (2 hours)	1.5
Cleveland Cliffs Co. No. 2 wood creosote	1.4
Standard Chemical Co. No. 3 coal-tar creosote	0.6

Remarks.—Increasing the amount of sodium sulphide and the length of time of agitation for sulphidizing gave a higher recovery than in previous tests. Also, the grade of the product was improved.

Results of test 39.

[Head contained Au, 0.04 ounce per ton; Ag, 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.2	630.7	55.0	85.2
Tailing	Tr.	12.4	.....	13.5

Flotation agents.	Pounds per ton.
Sodium sulphide (8 hours)	1.5
Cleveland Cliffs Co. No. 2 wood creosote	1.4
Standard Chemical Co. No. 3 coal-tar creosote	.6

Remarks.—The results indicated that lengthening the time of agitation for sulphidizing to eight hours and keeping the amount (1.5 pounds per ton) of sodium the same, gave a recovery and grade about the same as in the preceding test, No. 37.

Results of test 41.

[Head contained Au, 0.04 ounce per ton; Ag, 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.16	551.7	55.0	92.2
Tailing	Tr.	12.7	.....	.....

Flotation agents.	Pounds per ton.
Sodium sulphide (1 hour)	2.0
Cleveland Cliffs No. 2 wood creosote	1.4
Standard Chemical Co. No. 3 coal-tar creosote	.6

Remarks.—Sulphidization with 2 pounds of sodium sulphide seemed to give a higher recovery than the use of 1 pound. For comparison see test No. 30, on page 58. The grade of product was about the same.

Results of test 44.

[Head contained Au, 0.04 ounce per ton; Ag, 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.2	655.5	55.0	90.2
Tailing	Tr.	12.3	.....	13.4

Flotation agents.	Pounds per ton.
Sodium sulphide (8 hours)	2.0
Cleveland Cliffs No. 2 wood creosote	1.4
Standard Chemical Co. coal-tar creosote	.6

Remarks.—Using 2 pounds of sodium sulphide and increasing the time of sulphidizing to eight hours seemed to improve the grade of product somewhat, but the recovery of silver remained about the same. For comparison see the preceding tests Nos. 39 and 41.

Results of test 51.

[Head contained Au, 0.04 ounce per ton; Ag, 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.27	888.1	51.3	81.5
Tailing	Tr.	15.7	.....	17.8

Flotation agents.	Pounds per ton.
Sodium sulphide (1 hour)	2.0
Cleveland Cliffs Co. No. 2 wood creosote	.75
Standard Chemical Co. No. 3 coal-tar creosote	.3

Remarks.—Four times as much material (4,000 grams) was used as in test No. 41. (*See* p. 59.) The amount of sodium sulphide was the same as in that test, but only half the quantity of flotation oils was used. The results indicated a fair product but a relatively low recovery.

Results of test 52.

[Head contained Au, 0.04 ounce per ton; Ag. 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.25	819.5	57.5	93.1
Tailing	Tr.	5.8	.....	6.4

Flotation agents.	Pounds per ton.
Sodium sulphide (8 hours)	2.0
Cleveland Cliffs Co. No. 2 wood creosote	.75
Standard Chemical Co. No. 3 coal-tar creosote	.3

Remarks.—Increasing the time of sulphidizing seemed to effect a higher recovery of the silver, but the grade of product remained about the same as for test No. 51. The results indicated a fair product and good recovery.

Results of test 53.

[Head contained Au, 0.04 ounce per ton; Ag, 81.4 ounces per ton.]

Grade of products.	Assay of products.		Recoveries.	
	Au.	Ag.	Au.	Ag.
	Ounces per ton.	*Ounces per ton.*	*Per cent.*	*Per cent.*
Concentrate	0.79	1,425.5	49.4	81.4
Tailing	Tr.	13.0	.....	15.2

Flotation agents.	Pounds per ton.
Sodium sulphide (8 hours)	2.0
Sodium cyanide	.5
Cleveland Cliffs Co. No. 2 wood creosote	.75
Standard Chemical Co. No. 3 coal-tar creosote	.3

Remarks.—Comparison of these results with those of the preceding test, No. 52, seems to indicate that the addition of sodium cyanide improved the grade of the product but towered the recovery.

CONCLUSIONS.

On the basis of the experimental work on this ore the following conclusions seem justified:

1. This ore is amenable to flotation.
2. Pretreatment of the ore by sulphidization with sodium sulphide improves the silver recovery.
3. Treatment of flotation tailings on tables would seem advisable if much of the silver mineral is oxidized, and might eliminate the sulphidizing of the ore.
4. Use of sodium cyanide with the flotation agents seems to improve the grade of product.
5. It would seem advisable to make first a high recovery of silver without cyanide, then to retreat the first flotation concentrate with a small quantity of cyanide in order to improve the grade of the product.

TESTS OF A GOLD AND SILVER BEARING COPPER ORE.

DESCRIPTION OF ORE.

The work on this ore included experiments to ascertain the flotation agents best suited to effecting a good grade of product and a high recovery of the copper as well as the gold and silver.

In general, the four samples of ore submitted for investigation contained principally copper in the form of chalcopyrite, with minor amounts of bornite and chalcocite, and pyrite in a quartzitic gangue. Other minerals identified were malachite and azurite. The quartz gangue of samples 2 and 4 was more or less coated with iron rust. Relatively large pieces of clean chalcopyrite or bornite were not com-

mon, most of the copper-bearing minerals being finely disseminated through the gangue. Chemical analyses were made of each sample with the following results:

Chemical analyses of the ore.

	Sample 1.	Sample 2.	Sample 3.	Sample 4.
Cu.....per cent..	3.0	1.4	3.0	1.8
Fe.....do....	5.7	3.2	5.4	3.6
Pb.....do....	Tr.			
Zn.....do....	.2	.4	1.1	.4
S.....do....	2.5	1.2	2.8	2.2
Au.....ounces per ton..	.12	.2	.32	.65
Ag.....do....	1.26	.49	2.6	2.35
CaO.....per cent..	6.0	7.4	7.2	4.3
MgO.....do....	.26	.7	.5	.2
Al_2O_3.....do....	6.1	7.0	4.1	2.8
SiO_2.....do....	74.6	77.9	75.0	86.1

Examination of polished sections of this ore under the microscope indicated that it was composed chiefly of copper-bearing sulphides with chalcopyrite as the predominating mineral.[4] The chalcopyrite was considerably fractured and was cut by numerous veins and stringers filled with chalcocite of the so-called "blue" variety. In addition to the sulphides, the ore carried copper in the form of the carbonates malachite and azurite, which were present in only small amounts in the samples examined microscopically. Small amounts of hematite and magnetite were also noted. Under the microscope the crushed ore grains, represented by samples of the concentration products, appeared free from gangue and the minerals separated from each other, nothing that would hinder successful flotation being found.

Plate VIII, *B* (p. 51), a photomicrograph of a polished surface of the ore, shows the relation of the chalcopyrite and chalcocite, the latter being the darker and occurring in fractures and veinlets in the chalcopyrite.

SCREEN ANALYSIS.

Owing to the similarity in copper and iron content, samples 1 and 3 were mixed, as well as 2 and 4. Head samples of these were assayed and the results taken as a basis for calculations in the ensuing tests. The results of these assays were as follows:

Analyses of mixed samples.

	Samples 1 and 3.	Samples 2 and 4.
Copper.....per cent..	3.0	1.7
Iron.....do....	5.0	3.1
Gold.....ounces per ton..	.24	.36
Silver.....do....	1.54	1.35

[4] Microscopic examination made by R. E. Head, U. S. Bureau of Mines, Salt Lake City, Utah.

Samples of lots 1 and 3 were taken for a screen analysis, each screen product being assayed to determine the distribution of copper and iron. The screen analysis was made in a Tyler Ro-Tap shaking machine. Results are given in Table 2.

TABLE 13.—*Screen analysis of samples 1 and 3 of the copper ore.*

[Head contained Cu, 3 per cent; Fe, 5.5 per cent.]

Size of screen opening.			Weights.		Assays (per cent).		Percentage of total head content.		Cumulative per cent of total head content.	
Mesh.	Millimeters.	Inches.	Per cent.	Cumulative per cent.	Cu.	Fe.	Cu.	Fe.	Cu.	Fe.
On 28	0.589	0.232	65.2	.....	2.7	5.5	58.9	65.3	.....	.....
35	.417	.0164	8.8	74.0	3.0	5.5	8.7	8.7	67.6	74.0
48	.295	.0116	6.2	80.2	3.2	5.2	6.7	5.8	74.3	79.8
65	.208	.0082	4.7	84.9	3.3	5.5	4.7	4.7	79.0	84.5
100	.147	.0058	3.2	88.1	3.5	6.1	3.7	3.5	82.7	88.0
150	.104	.0041	3.0	91.1	3.7	5.7	3.3	3.1	86.0	91.1
200	.074	.0029	.8	91.9	3.5	6.3	1.0	.9	87.0	92.0
Through 200	.074	.0029	7.2	99.1	4.2	6.7	10.7	8.4	97.7	100.4
Loss or error by difference	.....	.....	.9	.....	.....	.....	+2.3	−0.4	.....	.....
Total	.....	.....	100.0	.....	.....	.....	100.0	100.0	.....	.....
Head	.....	.....	.....	.....	3.0	5.5	.....	.....	.....	.....

EXAMINATION OF SCREEN PRODUCTS.

Products on 28 and 35 mesh screens.—A small amount of clean chalcopyrite could be seen, although most of the mineral was combined with quartz. A few pieces of quartz stained with oxides of copper and iron were likewise noted.

Products on 48 and 65 mesh screens.—Most of the chalcopyrite, pyrite, and quartz minerals were free, although a small number of mineral particles were still mechanically combined.

Products on 100-mesh screen.—Practically no mechanically combined mineral particles were visible. In addition to the minerals already mentioned malachite and bornite were noted. All particles seemed to have more of a flat and angular shape than those in the coarser products.

Products on 150 and 200 and through 200 mesh screens.—No combined mineral particles were seen.

This examination of the various screen products indicated the advisability of crushing the material through a 65-mesh screen for flotation, as practically no combined mineral was observed in the material on the 100-mesh screen.

RESULTS OF FLOTATION TESTS.

The same procedure was followed as in previous tests. The results from a few of the better tests on this ore are given below:

Results of test 12.

[Head contained Cu, 3 per cent; Fe, 5 per cent; Au, 0.28 ounce per ton; Ag, 1.58 ounces per ton.]

Grade of products.	Assay of products.				Recoveries.			
	Cu.	Fe.	Au.	Ag.	Cu.	Fe.	Au.	Ag.
	Per cent.	*Per cent.*	*Ounces per ton.*	*Ounces per ton.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Concentrate	21.4	20.2	1.24	11.9	83.4	47.3	51.8	87.4
Tailing	.8	2.9	.....	.....	21.0	50.5	.....	.....

Flotation agents.

	Pounds per ton.
Sodium hydroxide	2.0
Mixture (1:4) of Vancouver (dark) coal-tar creosote and wood alcohol	1.5
General Naval Stores Co. No. 5 s. d. pine oil	0.08

Remarks.—A fair grade of copper concentrate and a good recovery of the copper and silver were obtained, but the gold recovery was low.

Results of test 14.

[Head contained Cu, 3 per cent; Fe, 5 per cent; Au, 0.28 ounce per ton; Ag, 1.58 ounces per ton.]

Grade of products.	Assay of products.				Recoveries.			
	Cu.	Fe.	Au.	Ag.	Cu.	Fe.	Au.	Ag.
	Per cent.	*Per cent.*	*Ounces per ton.*	*Ounces per ton.*	*Per cent.*	*Per cent*	*Per cent.*	*Per cent.*
Concentrate	18.8	19.4	1.24	10.5	87.8	54.4	62.2	93.0
Tailing	.5	2.9	.....	.2	14.3	50.0	.....	10.8

Flotation agents.

	Pounds per ton.
Barrett Co. No. 633 coal-tar creosote	0.8
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.6

Remarks.—The grade of the copper concentrate was fair and the recovery of the copper and silver was good, but the recovery of gold was low.

Results of test 16.

[Head contained Cu, 3 per cent; Fe, 5 per cent; Au, 0.28 ounce per ton; Ag, 1.58 ounces per ton.]

Grade of products.	Assay of products.				Recoveries.			
	Cu.	Fe.	Au.	Ag.	Cu.	Fe.	Au.	Ag.
	Per cent.	*Per cent.*	*Ounces per ton.*	*Ounces per ton.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Concentrate	23.2	24.9	1.72	12.6	77.5	50.0	61.0	79.0
Middling	7.4	9.1	.4	1.9	10.4	5.2	5.4	11.4
Tailing	.2	2.9	Tr.	.16	5.7	50.0	.....	8.8

Flotation agents.

	Pounds per ton.
Sodium hydroxide	1
Mixture (1:4) of Vancouver coal tar (heavy) and wood alcohol	1

Remarks.—The grade of the copper concentrate was good, but the recovery of copper was only fair.

Results of test 17.

[Head contained Cu, 3 per cent; Fe, 5 per cent; Au, 0.28 ounce per ton; Ag, 1.58 ounces per ton.]

Grade of products.	Assay of products.				Recoveries.			
	Cu.	Fe.	Au.	Ag.	Cu.	Fe.	Au.	Ag.
	Per cent.	*Per cent.*	*Ounces per ton.*	*Ounces per ton.*	*Per cent.*	*Per cent.*	*Ounces per ton.*	*Ounces per ton.*
Concentrate	20.2	20.9	1.64	9.1	83.4	52.0	71.4	71.5
Middling	2.9	6.6	.20	2.0	4.3	5.8	3.6	5.1
Tailing	.4	3.0	Tr.	.05	11.0	49.5	.....	26.0

Flotation agents.

	Pounds per ton.
Sodium hydroxide	1.0
Imperial fuel oil	1.0
Pensacola Tar & Turpentine Co. No. 400 wood creosote oil	.8

Remarks.—The grade of the copper concentrate and the recoveries of copper, gold, and silver were fair.

CONCLUSIONS.

On the basis of the experimental work on this ore the following conclusions seem justified:

1. This copper ore, on the basis of the tests on the sample, is amenable to flotation.
2. Copper concentrate of good grade with high recoveries of the copper and silver are possible by flotation.
3. The silver and gold seem to follow the copper.
4. Mechanical agitation machines will give good results.
5. A pulp density of 3 of water to 1 of ore seems to be best.
6. An alkaline pulp responds more readily to flotation than an acid pulp.

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